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Publication of the Journal

Readers of the *Journal* living in Britain can hardly fail to have guessed the reason for the delay in appearance of this issue; the *Journal* is but one amongst many British periodicals which have recently been forced to suspend or cease publication. To those members or subscribers overseas who are unaware of the situation we must explain that a large sector of the printing industry in this country has recently been shut down as a result of a labour dispute. The Society's printer was among the firms affected. Although the B.I.S. itself was not, of course, a party in the dispute, the Society has naturally suffered considerably from its existence.

The bulk of the material in the present issue would originally have comprised the May-June (No. 3) issue of the *Journal*. It was planned to follow this with a special Congress Issue (July-August, No. 4), which would have contained (in addition to its normal content of technical papers, news and *Astronautical Abstracts*) articles and other features of special interest to participants at the Tenth International Astronautical Congress and the British Commonwealth Spaceflight Symposium being held at Church House, London, at the end of August.

The printing dispute made this quite impossible. The uncertainty as to how long the dispute would continue, coupled with the fact that many firms are not equipped to undertake the printing of mathematical texts, ruled out the possibility of printing the special issue at another works; the present issue had already reached an advanced stage of production. It was also considered undesirable to forego quality by issuing an emergency publication produced by duplicating or similar processes, although had the dispute been prolonged much longer it might have been necessary to reconsider these decisions.

In order to regularize the publication of the *Journal* as rapidly as possible, this present issue will nominally cover the period May to August and be regarded as a "double number" (Nos. 3-4 of Volume 17), although not twice the usual size. The "missing pages" will be made up by increasing the size of the remaining two issues due to appear this year.

Our thanks must be expressed to the many authors who are patiently waiting for the appearance of their contributions. Every endeavour will be made to speed up publication, though initial difficulties will be experienced owing to the backlog of work from all the printer's customers. We would also like to apologise to the many advertisers who had been promised space in the special Congress issue.

Everyone who participated in either the Commonwealth Spaceflight Symposium or the I.A.F. Congress is receiving a copy of this issue; full reports of both meetings will appear soon in ***Spaceflight.***

G. V. E. THOMPSON.

AN APPLICATION OF DYNAMIC PROGRAMMING TO THE DETERMINATION OF OPTIMAL SATELLITE TRAJECTORIES *

By RICHARD BELLMAN,† Ph.D. and STUART DREYFUS,† B.S.
(Communication from The Rand Corporation)

ABSTRACT

We consider a simplified satellite trajectory problem, corresponding to a flat Earth assumption, first treated by Okhotsimskii and Eneev.[1,2] We present a numerical solution based upon the functional equation technique of dynamic programming, and a proof of the fundamental result in the analytic solution.

The same computational approach can be applied to more realistic trajectory problems.

I. INTRODUCTION

In this paper we wish to consider the problem of determining optimal satellite trajectories. To illustrate the general techniques of dynamic programming, we shall consider in detail a simplified satellite trajectory problem, posed and treated by D. E. Okhotsimskii and T. M. Eneev in a paper originally published in Russian,[1] and then in English translation.[2]

Despite superficial evidence of the correctness of their theories and results, it would appear that the mathematical argument in their papers is at best incomplete. One purpose of this paper is to deduce one of their principal results rigorously using standard variational arguments. What is rather interesting is that we arrive at a variational problem of unconventional type which has not been treated to any extent in the literature.

The principal part of our paper is devoted to the computational solution of the problems by means of the functional equation technique of dynamic programming. We shall present some numerical results. The importance of this approach lies in the fact that we can solve in the same manner variational problems which defy precise analysis.

II. THE SIMPLIFIED PROBLEM

We wish to ascertain the thrust control policy and propellent consumption regime which will put a satellite into orbit at a specified altitude with maximum horizontal component of velocity.

Essential simplifications arise from the neglect of aerodynamic forces and the assumption that the terrestial gravitational field is plane-parallel.

Determination of paths of minimum propellent, maximum altitude, and so on, can be treated along the same lines as the following discussion.

III. MATHEMATICAL FORMULATION

The equations of motion of a satellite travelling over a flat Earth in a Cartesian coordinate system will be taken to be

$$\left.\begin{aligned} \frac{du}{dt} &= p\cos\phi, & \frac{dw}{dt} &= p\sin\phi - g, \\ \frac{dy}{dt} &= w, & \frac{dx}{dt} &= u \end{aligned}\right\} \quad .. \quad (1).$$

Here

(*a*) x and y are, as usual, the horizontal and vertical coordinates,

(*b*) u and w are the horizontal and vertical projections of velocity,

(*c*) p is the magnitude of acceleration due to reaction force,

(*d*) ϕ is the inclination of the thrust to the horizontal.

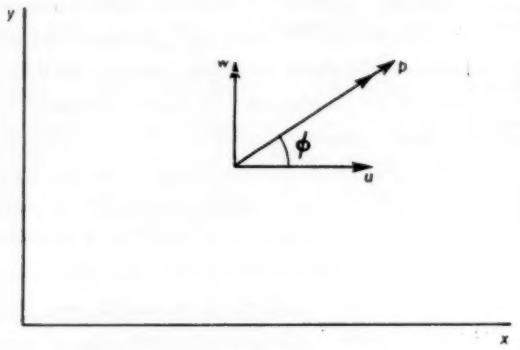

FIG. 1.

If we introduce the quantity V as the velocity available to the satellite in the idealized case of no gravitational force, we obtain the relation

$$\frac{dV}{dt} = p \quad .. \quad .. \quad .. \quad (2).$$

The variable V will be a monotone function of the quantity of propellent. Since

$$p = \frac{gP}{M} \quad .. \quad .. \quad .. \quad (3)$$

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where P is the thrust, and

$$P = -\frac{c}{g}\frac{dM}{dt} \quad .. \quad .. \quad (4)$$

where M is the mass and c is the exit velocity of the gases, we can solve for M in terms of the "ideal available velocity," V, obtaining the equation

$$M = M_e e^{V/c} \quad .. \quad .. \quad (5)$$

where M_e is the mass of the empty rocket.

The equations of motion, (1), together with (5) preceding, which yields mass as a function of V, and (3) above, giving acceleration in terms of thrust and mass, enable us to determine optimal inclinations and optimal magnitude of thrust as functions of V. In the next section we shall consider the associated variational problem.

IV. VARIATIONAL FORMULATION

A direct statement of the problem of determining optimal thrust and inclination leads to immediate difficulties because of the linearity of the equations and criterion function. An optimal policy would consist of either zero or infinite accelerations. Since this last is physically meaningless, in order to pose a sensible variational problem we impose a constraint of maximum possible thrust, Q. Furthermore, in these initial sections we shall agree to burn all the propellent at maximum allowable rate and then coast.

This assumption will not be made in later sections, where we obtain a direct computational solution using dynamic programming techniques. As will be seen, even under these simplifying assumptions, we are led to variational problems of some novelty and interest.

With the foregoing assumptions, the problem posed verbally in Section II becomes that of determining the inclination function $\phi(V)$ which maximizes

$$J(\phi) = \int_{V_0}^{0} \cos\phi \, dV \quad .. \quad .. \quad (6)$$

subject to the restriction that

$$\int_{V_0}^{0} \left(\frac{dy}{dV} + \frac{w}{g}\frac{dw}{dV}\right) dV = H \quad .. \quad (7)$$

and the relations in Equations (1)–(5). Here

(*a*) H is the prescribed altitude,
(*b*) V_0 is the initial ideal velocity.

The functional in (7) evaluates the altitude gained during burning together with the altitude obtained after burnout due to the vertical component of velocity at burnout.

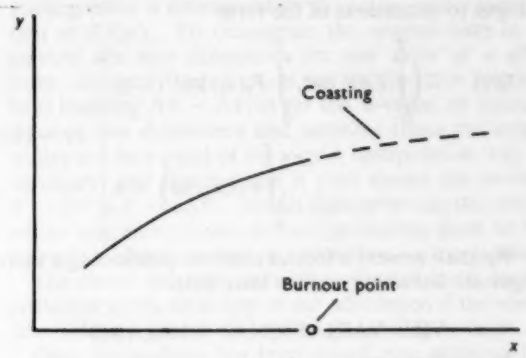

FIG. 2.

V. PRELIMINARY TRANSFORMATION

Referring to the equations of (1) we see that the constraint in Equation (7) may be written in the form:

$$\int_{V_0}^{0} \frac{w \sin\phi}{g} \, dV = H \quad .. \quad .. \quad .. \quad (8)$$

Turning back to (1), we may write

$$w(V) = w_0 + \int_{V_0}^{V} \left(\sin\phi - \frac{g}{p}\right) dV \quad .. \quad .. \quad (9)$$

Using this relation in (8), we obtain the relation

$$\int_{V_0}^{0} \sin\phi \, r(V) dV + \frac{1}{2g}\left(\int_{V_0}^{0} \sin\phi dV\right)^2 = H, \quad .. \quad (10)$$

where the function $r(V)$ is given by

$$r(V) = \frac{w_0}{g} - \int_{V_0}^{V} \frac{dV}{p} = \frac{w_0}{g} - \frac{cM_e}{gP}\left(e^{V/c} - e^{V_0/c}\right)$$
$$= k_1 + k_2 e^{V/c} \quad .. \quad .. \quad (11)$$

where k_1 and k_2 are constants.

VI. DISCUSSION

We thus obtain the problem of maximizing $J(\phi)$, as given by (6), subject to the constraint of (10) above. This is representative of an interesting class of variational problems which do not appear to have been discussed in any detail heretofore.

The general problem would be that of maximizing a functional

$$J_1(y) = \int_0^T F_1(x,y)dt \quad .. \quad .. \quad .. \quad (12)$$

subject to constraints of the form

$$\left.\begin{aligned} J_2(y) = G\Big(&\int_0^T F_2(x,y)dt, \int_0^T F_3(x,y)dt, \ldots, \\ &\ldots, \int_0^T F_N(x,y)dt\Big) = k \end{aligned}\right\} \quad .. \quad (13)$$

We shall present a formal analysis, postponing a more rigorous discussion until a later date.

VII. VARIATIONAL ANALYSIS

As usual, we set

$$\phi = \bar{\phi} + \epsilon\psi, \qquad .. \quad .. \quad (14)$$

where ϵ is an infinitesimal. We have

$$J(\phi) = J(\bar{\phi}) - \epsilon\int_{V_0}^{0} \psi \sin\bar{\phi}\, dV \quad .. \quad .. \quad (15)$$

and (10) yields

$$\int_{V_0}^{0} \psi\cos\bar{\phi}\, r(V)dV + \frac{1}{g}\left(\int_{V_0}^{0}\sin\bar{\phi}\, dV\right)\left(\int_{V_0}^{0}\psi\cos\bar{\phi}\, dV\right) = 0$$

.. (16).

Since ψ is arbitrary, it follows that there exists a constant λ such that:

$$\sin\bar{\phi} = \lambda\left[r(V)\cos\bar{\phi} + \frac{1}{g}\left\{\int_{V_0}^{0}\sin\bar{\phi}\, dV\right\}\cos\bar{\phi}\right] \quad .. \quad (17)$$

Since $\int_{V_0}^{0}\sin\bar{\phi}\, dV$ is a constant, albeit unknown, and

$$\frac{d}{dt}\, r(V) = k_2\frac{d}{dt}\, e^{V/c} = \frac{k_2}{c}\, e^{V/c}\frac{dV}{dt}$$

$$= \frac{k_2}{c}e^{V/c}\frac{gP}{M_e}e^{-V/c} = \frac{gP}{M_e c}\cdot\frac{M_e c}{gP} = 1 \quad .. \quad (18)$$

it follows that we obtain the important conclusion that the optimal policy, $\bar{\phi}$, is characterized by the property that

$$\frac{d}{dt}\tan\bar{\phi} = \lambda \quad .. \quad .. \quad .. \quad (19)$$

a constant.

This agrees with the result claimed in reference 2.

VIII. DYNAMIC PROGRAMMING APPROACH—1

Let us now see how we can employ the functional equation approach of dynamic programming to obtain a computational solution. The basic idea is to regard the problems of the calculus of variations as particular examples of multi-stage decision processes of continuous type. This approach is discussed in some detail by Bellman,[3] and applied to optimal trajectory problems by Cartaino and Dreyfus.[4]

The state variables are altitude y, vertical component of velocity w, and ideal available velocity V. Consequently, we introduce the function:

$f(V,w,y)$ = the additional horizontal velocity obtained starting at altitude y, vertical component of velocity w and ideal available velocity V, and using an optimal policy.

Referring to the defining equations of motion, (1), and using the Principle of Optimality as in reference 3 or 4, we obtain the functional equation:

$$f(V,w,y) = \operatorname*{Max}_{\phi,P}\Big[\cos\phi\Delta V + f\Big(V-\Delta V, w+\frac{dw}{dV}\Delta V, y+\frac{dy}{dV}\Delta V\Big)\Big]$$

$$= \operatorname*{Max}_{\phi,P}\Big[\cos\phi\Delta V + f\Big\{V-\Delta V, w+\Big(\sin\phi - \frac{M_e e^{V/c}}{P}\Big)\Delta V, y+\frac{wM_e e^{V/c}}{gP}\Delta V\Big\}\Big]$$

.. (20)

where ΔV is regarded as a small quantity.

Letting V assume only a finite set of values $0,\Delta V, 2\Delta V, \ldots, N\Delta V$, we see that the computation becomes that of determining a sequence of functions of two variables $f_N(w,y) \equiv f(N\Delta,w,y)$, using equation (20).

IX. DYNAMIC PROGRAMMING APPROACH—2

In order to simplify the computation, we use a Lagrange multiplier formalism, as discussed by Bellman,[5] to reduce the problem to one of determining a sequence of functions of one variable.

In place of maximizing $J(\phi)$ subject to the constraint of equation (8), we consider the problem of maximizing

$$\int_{V_0}^{0}\cos\phi dV + \lambda\int_{V_0}^{0}\frac{dy}{dV}dV \quad .. \quad .. \quad (21)$$

subject to the constraints of the equations of motion. Here λ is the Lagrange parameter.

The new functional equation for the maximum value is

$$f(V,w) = \operatorname{Max}\Big\{\operatorname*{Max}_{\phi,P}\Big[\cos\phi\Delta V + \frac{\lambda wM_e e^{V/c}}{gP}\Delta V + f\Big(V-\Delta V, w+\Big(\sin\phi-\frac{M_e e^{V/c}}{gP}\Big)\Delta V\Big), \lambda w\Delta t + f(V, w-g\Delta t)\Big\}$$

.. (22)

where the second alternative within the Max { } represents a decision to coast for a small time interval Δt.

The parameter λ is adjusted until the altitude constraint of equation (7) is met. By using the Lagrange parameter, we have partitioned a problem originally involving a sequence of functions of *two* variables into a set of problems involving functions of *one* variable. The gain in computing time and effort is considerable.

X. COMPUTATIONAL ASPECTS

The numerical solution is obtained by iterating the recurrence equation (22) backwards from the known final values. The calculation is begun by observing that, if burnout occurs with a vertical component of velocity w, the additional altitude obtained during coasting will be $w^2/2g$ and the additional horizontal velocity will be zero. Hence $f(0,w) = \lambda w^2/2g$. A table containing $f(0,w)$ for a range of w values (we do not yet know to what burnout value of w the optimal policy will lead) is stored in the high-speed memory of the computer.

This tabular function is now used to determine a new function, $f(\Delta V,w)$, the total additional horizontal velocity plus λ times the altitude that can be attained starting with a small quantity ΔV of "available velocity (propellent)" and vertical velocity component w. This calculation is performed using Equation (7). We actually evaluate the gain associated with choices of different ϕ's and P's, and compare this with the return from a decision to coast. On this basis we pick the optimal decision. The return from this decision is recorded in the computer memory as the value of $f(\Delta V,w)$ for the particular value of w considered. A second table is constructed giving the optimal decision that yielded $f(\Delta V,w)$. A third table, $J(\Delta V,w)$, is maintained giving the total altitude gained when following an optimal path starting from $(\Delta V,w)$. Since we are flying so as to maximize horizontal velocity plus λ times altitude, this third table is just a convenient record that is not used in the calculation, but which, when the iteration of Equation (7) is finished, yields immediately the total altitude (and hence the horizontal velocity, $f(V,0) - \lambda J(V,0)$), gained by following an optimal trajectory.

Once the technique described above for calculating $f(\Delta V,w)$ using the table of $f(0,w)$ has been programmed for a computer, it is a simple matter to have the same code calculate $f(2\Delta V,w)$ from $f(\Delta V,w)$ and, finally, $f(V,w)$ from $f(V - \Delta V,w)$. Notice that at each stage of this computation only one table of the function f is needed to compute the next table in the sequence. Once a table has been computed and used in the calculation of the next table it can be printed by the computer and destroyed in memory. Hence the computer memory capacity required is determined by the number of discrete points chosen for the w-table, and does not depend on the fineness of the ΔV grid. The total time for a calculation depends linearly on the size of ΔV.

At the completion of the backwards iteration of Equation (7) one knows the horizontal velocity and altitude obtained by an optimal policy for the specified initial conditions. Also the initial decision for the starting point is determined by the nature of the calculation of $f(V,w)$. To reconstruct the optimal path in its entirety one now determines the new value of w after using the prescribed decision for the first ΔV interval. In calculating $f(V - \Delta V,w)$ for this w-value, an optimal decision was determined and recorded (since the actual w may not be a point of the w-grid, interpolation may be necessary) and this decision is used during the interval $V - \Delta V$ to $V - 2\Delta V$. In this manner we use the output of the sequence of calculations, processing them in the opposite order from that in which they were computed.

The above operation may be performed easily by the computer as the final step of the calculation if the requisite tables are stored on tape or punched into cards.

Once the problem has been solved, one examines the final altitude to determine if the required height was attained. A new value of the Lagrange multiplier λ is then calculated based upon previous values and results, and the calculation is repeated.

One calculation yields the optimal path, in terms of horizontal velocity $+ \lambda \times$ altitude, for a wide range of initial vertical components of velocity. This variety of results is of interest in problems where initial vertical velocity is not necessarily specified and the answers for a range of values is desired. Secondly, after several variations of λ, optimal trajectories to several different altitudes are known, yielding an interesting estimate of the trade-off between altitude and velocity along optimal trajectories.

XI. NUMERICAL RESULTS

For all calculations, we have assumed a hypothetical missile with the following characteristics:

Empty mass, $M_e = 5000$ lb.
Exhaust velocity, $c = 11{,}000$ ft./sec.
Maximum thrust, $P_{\max} = 300{,}000$ lb.,
Minimum thrust with engine on, $P_{\min} = 50{,}000$ lb.
Total ideal available velocity $= 30{,}000$ ft./sec.

These data imply a total weight at takeoff of 76,456 lb.

A value of λ of 0·00142 yielded a final altitude of approximately 450 miles with a horizontal component of velocity at this altitude of 26,300 ft./sec.

Various parameters and grid-sizes required for numerical solution were chosen as follows:

1. $\Delta V = 1000$. Therefore the recurrence relation was iterated 30 times.

2. $\Delta w = 50$. Each table of $f(V,w)$ contained 281 numbers, since w was allowed to assume value from 0 to 14,000.

3. $\Delta\phi = 0{\cdot}01$ radians. Admissible thrust angles were 0, 0·01, 0·02, . . ., $\pi/2$ radians.

4. Thrust could assume values 300,000, 250,000, 200,000, 150,000, 100,000, or 50,000.

These numbers were determined experimentally. They possess the property that a further refinement has little or no effect on the computed solution.

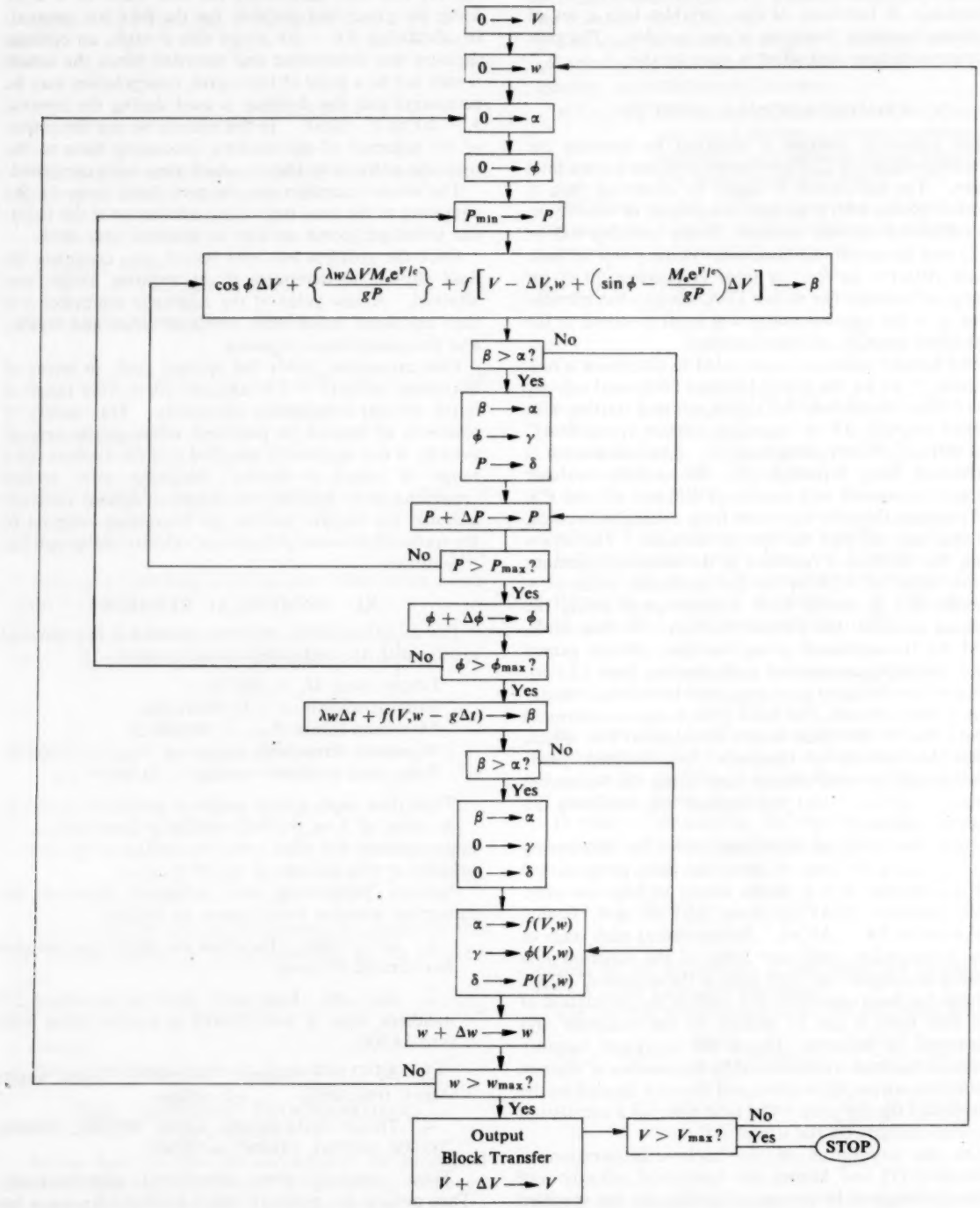
$0 \longrightarrow V$
$0 \longrightarrow w$
$0 \longrightarrow \alpha$
$0 \longrightarrow \phi$
$P_{\min} \longrightarrow P$
$\cos\phi\,\Delta V + \left\{\frac{\lambda w \Delta V M_e e^{V/c}}{gP}\right\} + f\left[V - \Delta V, w + \left(\sin\phi - \frac{M_e e^{V/c}}{gP}\right)\Delta V\right] \longrightarrow \beta$
$\beta > \alpha$?
No
Yes
$\beta \longrightarrow \alpha$
$\phi \longrightarrow \gamma$
$P \longrightarrow \delta$
$P + \Delta P \longrightarrow P$
No
$P > P_{\max}$?
Yes
$\phi + \Delta\phi \longrightarrow \phi$
No
$\phi > \phi_{\max}$?
Yes
$\lambda w \Delta t + f(V, w - g\Delta t) \longrightarrow \beta$
$\beta > \alpha$?
No
Yes
$\beta \longrightarrow \alpha$
$0 \longrightarrow \gamma$
$0 \longrightarrow \delta$
$\alpha \longrightarrow f(V,w)$
$\gamma \longrightarrow \phi(V,w)$
$\delta \longrightarrow P(V,w)$
$w + \Delta w \longrightarrow w$
No
$w > w_{\max}$?
Yes
Output
Block Transfer
$V + \Delta V \longrightarrow V$
$V > V_{\max}$?
No
Yes
STOP

FIG. 3

A condensed summary of the solution, as computed on the RAND JOHNNIAC computer in 20 minutes, is shown in Table I.

TABLE I

V, ft./sec.	Mass, lb.	h, ft.	w, ft./sec.	u, ft./sec.	ϕ, rad.	P, lb.	Time, sec.
30,000	76,456	0	0	0	0·560	300,000	0
25,000	48,529	16,045	1,514	4,279	0·523	300,000	33·3
20,000	30,803	57,720	3,306	8,625	0·501	300,000	54·4
15,000	19,552	106,344	5,259	13,020	0·490	300,000	67·8
10,000	12,410	152,954	7,330	17,436	0·480	300,000	76·3
5,000	7,877	192,848	9,464	21,871	0·480	300,000	81·7
burnout	5,000	224,920	11,650	26,313	0·472	300,000	85·1
end of coast	5,000	2,337,679	0	26,313	0	0	444·7

It should be noted that, although in this simplified study the rocket is flown at maximum thrust until burnout and the thrust direction obeys a simple law, the computational scheme assumes neither of these results. It is therefore applicable to more general problems that are not amenable to conventional mathematical analysis.

XII. FLOW-CHART

A flow diagram of the programme is shown in Fig. 3.

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ORBITS OF ARTIFICIAL SATELLITES*

By Professor WILLIAM T. THOMSON†

ABSTRACT

A study of general motion under an inverse square central force has shown that the orbits of artificial satellites can be specified by three non-dimensional parameters at rocket burnout. The conditions for circular, elliptical, parabolic and hyperbolic orbits are discussed, and expressions giving the periods of closed orbits in terms of the parameters are derived.

I. INTRODUCTION

RECENT technological developments in the fields of rocket propulsion and guidance have made possible the launching of artificial satellites into one of the many possible space orbits. Once a body has been put into an orbit beyond the influence of the atmosphere, its total energy remains constant and equal to that at rocket burnout. The total energy establishes the class of orbit, which may vary from an ellipse to a hyperbola, the circle and the parabola being limiting cases. However, an infinite number of orbits of the same class are possible for a given total energy at a specified point in space, and the heading angle of the velocity vector at rocket burnout must specify the particular orbit from the many possible orbits passing through this point.

II. GENERAL MOTION UNDER AN INVERSE SQUARE CENTRAL FORCE

We will assume that the satellite is launched to a sufficient height beyond the influence of the atmosphere. The equations of motion are then:

Radial force $$\ddot{r} - r\dot{\theta}^2 = -\frac{\mu}{r^2} \quad .. \quad .. \quad (1)$$

Force normal to radius

$$r\ddot{\theta} + 2\dot{r}\dot{\theta} = \frac{1}{r}\frac{d}{dt}(r^2\dot{\theta}) = 0 \quad .. \quad .. \quad (2)$$

As a consequence of equation (2) we arrive at the result:

$$r^2\dot{\theta} = \lambda \quad .. \quad .. \quad .. \quad (3)$$

where λ is a constant equal to twice the area swept out by the radial line per unit of time.

By the substitution of $r = 1/u$, the independent variable t is changed to the independent variable θ, and equation (1) becomes:

$$\frac{d^2u}{d\theta^2} + u = \frac{\mu}{\lambda^2} \quad .. \quad .. \quad .. \quad (4)$$

with the general solution,

$$u = \frac{\mu}{\lambda^2} + C\cos(\theta - \theta_1) \quad .. \quad .. \quad (5)$$

We can next consider the energy relationship per unit mass. The kinetic energy per unit mass is

$$T = \frac{1}{2}v^2 = \frac{1}{2}[\dot{r}^2 + (r\dot{\theta})^2] = \frac{\lambda^2}{2}\left[\left(\frac{du}{d\theta}\right)^2 + u^2\right] \quad .. \quad (6)$$

With no dissipation, the sum of the kinetic and potential energies per unit mass is a constant equal to the total energy per unit mass at burnout.

$$E = T + V \quad .. \quad .. \quad .. \quad (7)$$

Equation (6) can now be written as

$$\left(\frac{du}{d\theta}\right)^2 + u^2 = \frac{2(E - V)}{\lambda^2} \quad .. \quad .. \quad (8)$$

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which is the energy equation accompanying equation (4).

For the launching of satellites, the total energy with respect to the Earth's surface is of interest, so that we will take the potential energy to be zero at the Earth's surface.

$$V = \int_R^r \frac{\mu}{r^2} dr = \frac{\mu}{R}\left(1 - \frac{R}{r}\right) = \frac{\mu}{R}(1 - Ru) \quad \ldots \quad (9)$$

Substituting equations (5) and (9) into equation (8), the constant C can be evaluated as

$$C^2 = \left(\frac{\mu}{\lambda^2}\right)^2\left[1 + \frac{2E\lambda^2}{\mu^2} - \frac{2\lambda^2}{\mu R}\right] \quad \ldots \quad \ldots \quad (10)$$

and by rotating the base line of $\theta = 0$ to perigee (point of minimum distance from the origin of r), equation (5) can be put in the final form,

$$u = \frac{1}{r} = \frac{\mu}{\lambda^2}(1 + e\cos\theta) \quad \ldots \quad \ldots \quad (11)$$

where

$$e = \sqrt{1 + \frac{2E\lambda^2}{\mu^2} - \frac{2\lambda^2}{\mu R}} \quad \ldots \quad \ldots \quad \ldots \quad (12)$$

This is the most general solution for the inverse square central force problem, and the class of orbit is established by the value of e as follows:

Hyperbola	if $e > 1$
Parbola	if $e = 1$
Ellipse	if $e < 1$, with perigee corresponding to $\theta = 0$
Circle	if $e = 0$
Ellipse	if $e < 0$, with apogee corresponding to $\theta = 0$

The value of e is determined by the initial conditions at rocket burnout, indicated by the subscript 0, and we will examine the problem without placing restrictions on e.

Letting r_1 be the perigee distance, equation (11) becomes

$$u = \frac{1 + e\cos\theta}{r_1(1 + e)} \quad \ldots \quad \ldots \quad (13)$$

$$\frac{\lambda^2}{\mu} = r_1(1 + e) \quad \ldots \quad \ldots \quad \ldots \quad (14)$$

From the kinetic energy and total energy, two additional equations can be obtained and expressed in non-dimensional form:

$$\left(\frac{rv^2}{\mu}\right) = 2 - \frac{r}{r_1}(1 - e) \quad \ldots \quad \ldots \quad (15)$$

$$\left(\frac{ER}{\mu}\right) = 1 - \frac{R}{2r}\left[2 - \left(\frac{rv^2}{\mu}\right)\right] \quad \ldots \quad (16)$$

III. INITIAL CONDITIONS

With these equations we will specify the initial values at burnout, which are shown in Fig. 1.

$r = r_0$ $\qquad$ $\beta = \beta_0$

$v = v_0$ $\qquad$ $\theta = \theta_0$

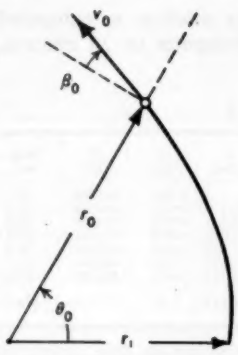

FIG. 1. Initial conditions

The components of the initial velocity are:

$$v_0\cos\beta_0 = r_0\dot{\theta}_0 = \frac{\lambda}{r_0}$$

$$v_0\sin\beta_0 = \dot{r}_0 = -\lambda\left(\frac{du}{d\theta}\right)_{\theta=\theta_0} = \frac{\mu e\sin\theta_0}{v_0 r_0\cos\beta_0}$$

From equation (11) we have at launch:

$$\frac{1}{r_0} = \frac{\mu(1 + e\cos\theta_0)}{v_0^2 r_0^2\cos^2\beta_0}$$

Solving for $e\sin\theta_0$ and $e\cos\theta_0$ and dividing, the angular position from perigee is found:

$$\tan\theta_0 = \frac{\left(\frac{r_0v_0^2}{\mu}\right)\sin\beta_0\cos\beta_0}{\left(\frac{r_0v_0^2}{\mu}\right)\cos^2\beta_0 - 1} \quad \ldots \quad (17)$$

Since the value of E is constant after burnout, equation (16) can now be written as:

$$\left(\frac{ER}{\mu}\right) = 1 - \frac{R}{2r_0}\left[2 - \left(\frac{r_0v_0^2}{\mu}\right)\right] \quad \ldots \quad (18)$$

From equations (12), (18), and $\lambda = r_0v_0\cos\beta_0$, the quantity e is found:

$$e^2 = \left[\left(\frac{r_0v_0^2}{\mu}\right) - 1\right]^2\cos^2\beta_0 + \sin^2\beta_0 \quad \ldots \quad (19)$$

Equations (17) and (19) are sufficient to completely establish the orbit for any initial condition, and equation (18) indicates the required energy.

IV. INTERPRETATION OF RESULTS

1. SPECIAL CASE $\beta_0 = 0$

We will first examine the special case where the satellite is launched with a zero heading angle, $\beta_0 = 0$. From equation (17) it is evident that $\theta_0 = 0$, so that $r_0 = r_1$. Equation (15) now becomes:

$$e = \left(\frac{r_0v_0^2}{\mu}\right) - 1 \quad \ldots \quad \ldots \quad (15^*)$$

where the (*) is used for the special case $\beta_0 = 0$, and (**) for the further restricted case of circular orbit. The quantity e and the total energy from equation (18) are plotted in Fig. 2 and 3, which clearly classify the type of orbit.

If we are able to launch a satellite with $\beta_0 = 0$ at a given value of r_0/R, as shown in Fig. 4, we would get a circular orbit ($e = 0$) only when $(r_0v_0^2/\mu) = 1$. The corresponding total energy is then:

$$\left(\frac{ER}{\mu}\right) = 1 - \frac{R}{2r_0} \quad \ldots \quad \ldots (18^{**})$$

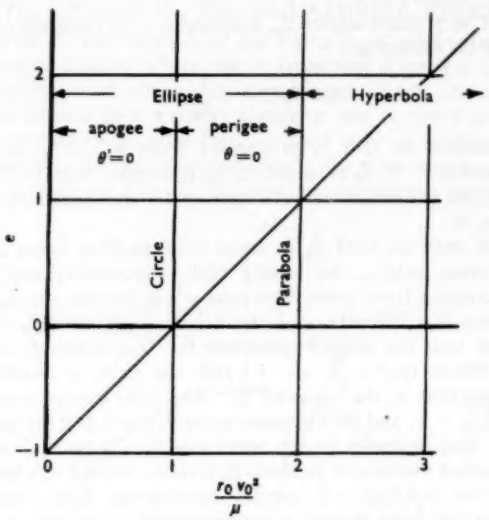

FIG. 2

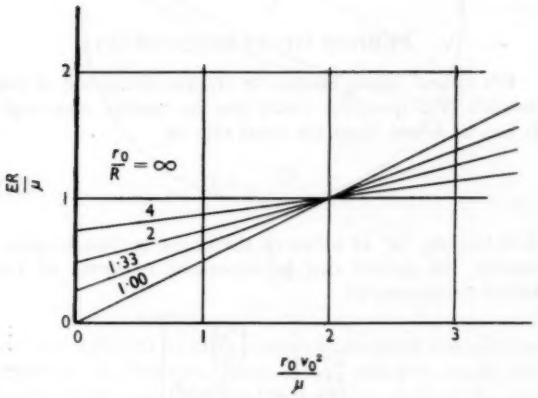

FIG. 3

If v_0 is then increased so that $r_0 v_0^2/\mu > 1$, the orbit will be an ellipse with e and ER/μ as determined from equations (15*) and (18) or from Fig. 2 and 3. For values of $r_0 v_0^2/\mu > 2$, the orbit will become a hyperbola, and the satellite will escape from the Earth, never to return. Thus $r_0 v_0^2/\mu = 2$ corresponds to the velocity of escape at height $r_0 = R + h$.

$$v_e = \sqrt{\frac{2\mu}{r_0}} = R\sqrt{\frac{2g_0}{r_0}} \quad .. \quad (20)$$

Considering the geometry of the elliptic orbit, the semi-major and semi-minor axes are:

$$\text{semi-major } \frac{a}{r_0} = \frac{1}{1-e} \quad .. \quad .. \quad (21)$$

$$\text{semi-minor } \frac{b}{r_0} = \sqrt{\frac{1+e}{1-e}} \quad .. \quad .. \quad (22)$$

The apogee distance is:

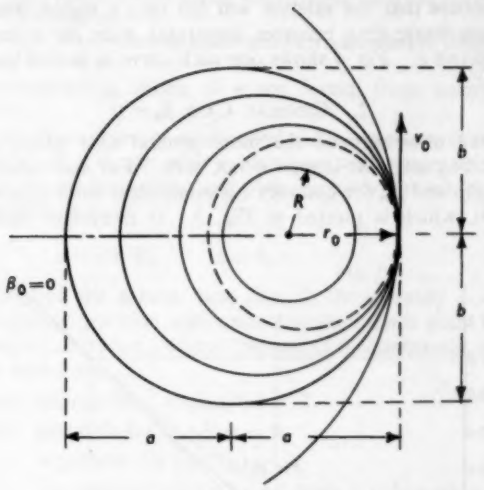

FIG. 4

$$\frac{r_a}{r_0} = \frac{1+e}{1-e} \quad .. \quad .. \quad .. \quad (23)$$

and in terms of the altitude h above the Earth's surface, the apogee and perigee altitudes are:

$$\frac{h_a}{R} = \frac{r_0}{R}\left(\frac{1+e}{1-e}\right) - 1 \quad .. \quad .. \quad (24)$$

$$\frac{h_p}{R} = \frac{r_0}{R} - 1 \quad .. \quad .. \quad .. \quad (25)$$

Numerical values for a few values of e are given below to illustrate that the elliptic orbits are nearly circular. The ratio of apogee to perigee altitudes, however, can be quite large. For an eccentricity of 0·20, this ratio is 6·50 when the launch height is $r_0/R = 1{\cdot}10$, or approximately 400 miles above the Earth's surface. It is interesting to note that the ratio of the semi-major to semi-minor axes is only 1·02, and that these results are attained by an increase of launching speed of only 9·6% above that of the circular orbit speed.

Calculations for Launching Altitude $r_0/R = 1{\cdot}10$

e	$\frac{1+e}{1-e}$	h_a/h_p	a/b	$\frac{r_0 v_0^2}{\mu}$	$\left(\frac{\text{Elliptic speed}}{\text{Circular speed}}\right)_{\text{at launch}}$
0·00	1·00	1·00	1·00	1·00	1·00
0·05	1·105	2·15	1·00+	1·05	1·025
0·10	1·22	3·40	1·007	1·10	1·05
0·20	1·50	6·50	1·02	1·20	1·096

We can next investigate the case $r_0 v_0^2/\mu < 1{\cdot}0$. Examination of equation (11) with negative e shows that we have an ellipse with the starting point corresponding to apogee, and perigee is at $\theta = 180°$. The speed is then not sufficient to balance the attractive force of the Earth, and the satellite distance r will diminish from its initial value r_0. With negative e, the centre of the ellipse falls between the origin and the launching point. It is evident from the previous set of

numbers that the satellite will fall into a region where atmospheric drag becomes important, even for a small negative e. Fig. 4 shows one such curve in dotted lines.

2. General Case $\beta_0 \neq 0$

We now examine the more general case where the heading angle at launch is not zero. For any value of $r_0v_0^2/\mu$ and β_0, the quantity e is established from equation (19), which is plotted in Fig. 5. It is evident that if

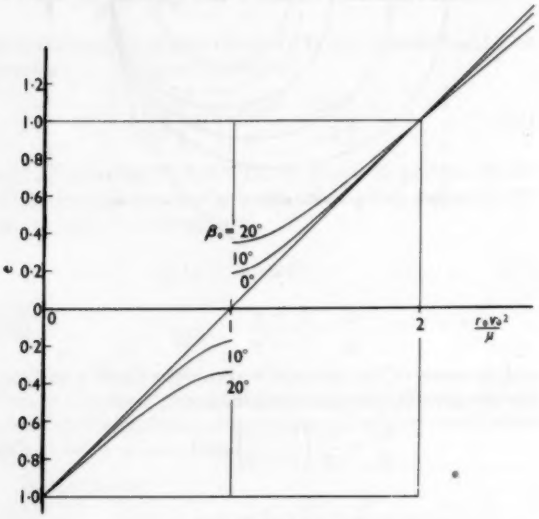

Fig. 5

$\beta_0 \neq 0$, e can never become zero, so that a circular orbit is not possible. The perigee position θ_0 with respect to the launch point is located by equation (17). The equation indicates that θ_0 is $\pi/2$ when $(r_0v_0^2/\mu)\cos^2\beta_0 = 1$. For $(r_0v_0^2/\mu)\cos\beta_0 < 1$ and $\beta_0 > 0$, θ_0 is in the second quadrant. For instance, if we launch at a very large positive angle β_0, the denominator of equation (17) is nearly -1, so that $\tan\theta_0$ approaches zero in the second quadrant, or θ_0 is slightly under 180°, and we have a very slender ellipse as shown in Fig. 6, or by equation (19).

To determine the effect of β_0 alone, we might take a case where the speed at launch is equal to that of the circular orbit, $(r_0v_0^2/\mu) = 1$, and vary β_0. The total energy ER/μ depends only on $r_0v_0^2/\mu$ and r_0/R, so that it will be the same for all orbits passing through the launch point with the same speed. For $\beta_0 = 0$ and $r_0v_0^2/\mu = 1$, we have a circle and θ_0 has no significance. For very small angles β_0, and $r_0v_0^2/\mu = 1$, equation (17) can be written as:

$$\tan\theta_0 \cong -\frac{1}{\beta_0}$$

therefore we find θ_0 proceeding from $\pi/2$ to π as β_0 increases. If β_0 is negative, θ_0 proceeds from $3\pi/2$ to 2π, all of which is consistent with the geometry of Fig. 6.

If next we hold β_0 at some fixed positive value and increase $r_0v_0^2/\mu$, we would find e increasing and θ_0 increasing from some value near $\pi/2$ in the first quadrant when $(r_0v_0^2/\mu)\cos^2\beta_0 > 1$, to $\pi/2$ at $(r_0v_0^2/\mu)\cos^2\beta_0 = 1$, and into the second quadrant for $(r_0v_0^2/\mu)\cos^2\beta_0 < 1$.

When $r_0v_0^2 = 2$, $e = 1$, and we have a parabola regardless of the value of β_0. The total energy is then $ER/\mu = 1$, and the reference angle θ_0 starts at 0 for small β_0 and increases to 90° when $\cos^2\beta_0 = \frac{1}{2}$ or $\beta_0 = 45°$. Further increase in β_0 shifts θ_0 into the second quadrant.

For $(r_0v_0^2/\mu) > 2$, similar conclusions hold, except that the orbit is now a hyperbola for all values of β_0, which can only change the reference angle θ_0.

V. Period of Closed Orbits

For closed orbits, ellipses or circles, the period of the satellite is a quantity which can be readily measured. It can be found from the areal rate as

$$\tau = \frac{2\pi}{\sqrt{\mu}}\, a^{3/2} \qquad \ldots \quad \ldots \quad (26)$$

Substituting "a" in terms of the non-dimensional parameters, the period can be expressed in terms of the initial conditions as

$$\tau = \frac{2\pi}{\sqrt{\frac{g_0}{R}}}\left[\frac{\left(\frac{r_0}{R}\right)}{2 - \left(\frac{r_0v_0^2}{\mu}\right)}\right]^{3/2} \qquad \ldots \quad (27)$$

or in terms of the total energy as

$$\tau = \frac{2\pi}{\sqrt{\frac{g_0}{R}}}\left[\frac{1}{2\left(1 - \frac{ER}{\mu}\right)}\right]^{3/2} \qquad \ldots \quad (28)$$

Thus we find that the period depends only on the total energy, and all orbits passing through a given point with the same velocity will have the same period, regardless of the heading angle.

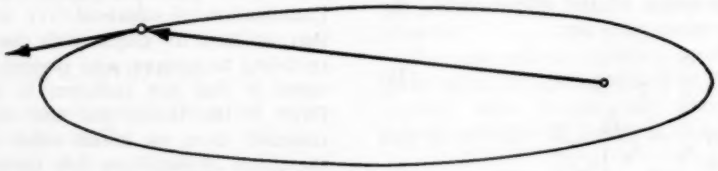

Fig. 6

VI. EFFECT OF THE EQUATORIAL BULGE

Due to the rotation of the Earth from west to east, there is a speed advantage in launching a satellite in a direction with an easterly component. Such an orbit will precess in a westerly direction due to the Earth's equatorial bulge, and thus a closed orbit is really not possible. The revolving satellite is like a gyroscope, and as shown in Fig. 7, its angular momentum vector,

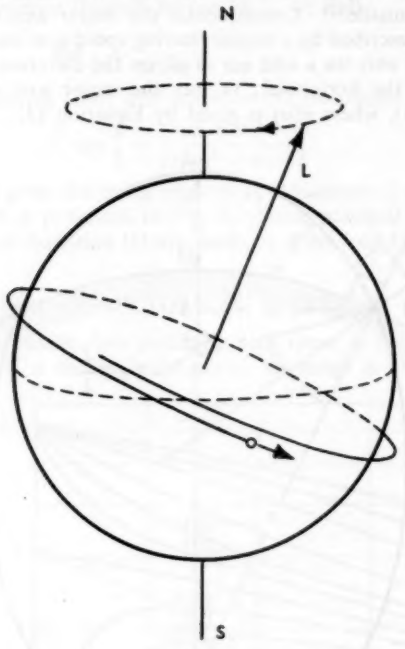

FIG. 7

perpendicular to its orbit plane and directed towards the northern hemisphere, must slowly revolve about the north polar axis due to the moment exerted by the excess mass over the sphere near the equator. The rate of precession will depend on the orbit angle with respect to the equator, and to a somewhat smaller extent on the altitude.

VII. CONCLUSIONS

(1) The orbits of artificial satellites are specified by three non-dimensional parameters at rocket burnout: r_0/R, $r_0v_0^2/\mu$, and β_0.

(2) A circular orbit is possible only under the condition $\beta_0 = 0$ and $r_0v_0^2/\mu = 1$, and the required energy is given by equation (18**).

(3) With $\beta_0 = 0$ and $r_0v_0^2/\mu \neq 1$, we have the following orbits:

(*a*) Ellipse with launch point corresponding to apogee if $0 < (r_0v_0^2/\mu) < 1$.

(*b*) Ellipse with launch point corresponding to perigee if $1 < (r_0v_0^2/\mu) < 2$.

(*c*) Parabola with launch point corresponding to perigee if $(r_0v_0^2/\mu) = 2$.

(*d*) Hyperbola with launch point corresponding to perigee if $(r_0v_0^2/\mu) > 2$.

Corresponding values of e are found from equation (15*).

(4) For values of $r_0v_0^2/\mu$ and ER/μ equal to that of (2) but $\beta_0 \neq 0$, the orbit is an ellipse with eccentricity e and the position of perigee with respect to launch point established from

$$e = \sin \beta_0, \qquad \tan \theta_0 = -\frac{1}{\tan \beta_0}$$

(5) For the general case $\beta_0 \neq 0$, the quantity e and the perigee position with respect to the launch point are established from equations (19) and (17) respectively, and the orbits are:

(*a*) ellipses for $0 < (r_0v_0^2/\mu) < 2$.

(*b*) parabola for $(r_0v_0^2/\mu) = 0$.

(*c*) hyperbola for $(r_0v_0^2/\mu) > 2$.

(6) The required energy for all cases is independent of β_0, and depends only on r_0/R and $r_0v_0^2/\mu$ as indicated by equation (18). For $ER/\mu > 1$, the orbit is hyperbolic and escape from the Earth is possible for all angles β_0 for which the orbit does not intersect with the Earth.

(7) When the orbit is an ellipse or circle, (ER/μ) is less than 1, and the period is established from equations (27) or (28).

(8) For the case $\beta_0 = 0$, the ratio of apogee to perigee heights above Earth surface may deviate greatly from unity, although the orbits are nearly circular.

(9) When $\beta_0 \neq 0$ elliptic orbits of large eccentricity are possible for large β_0.

(10) The orbit plane will precess due to the Earth's equatorial bulge.

LIST OF SYMBOLS

E = total energy per unit mass.
G = universal constant of gravitation.
L = angular momentum.
M = mass of Earth.
R = radius of Earth.
T = kinetic energy per unit mass.
V = potential energy per unit mass.
a = semi-major axis of ellipse.
b = semi-minor axis of ellipse.
e = defined in paper (eccentricity when orbit is ellipse).
g_0 = acceleration of gravity at Earth's surface, $h = 0$.
h = $r - R$ = altitude above Earth's surface.
h_a = apogee altitude (point of maximum r).
h_p = perigee altitude.
r = distance from centre of Earth.
r_1 = perigee distance (point of minimum r, corresponding to $\theta = 0$).
r_0 = rocket burnout distance.
u = $1/r$.
v = velocity.
v_0 = velocity at rocket burnout.
β_0 = heading angle at rocket burnout, measured from normal to r_0.
θ = angle of r from reference r_1.
θ_0 = angle of r_0 from reference r_1.
λ = twice areal rate, $2\,dA/dt$ = constant.
μ = $GM = g_0R^2$.
τ = orbital period.

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RANGE AND ACCURACY OF LONG-RANGE BALLISTIC MISSILES*

By IRVIN G. HENRY,† M.S., Fellow
(Communication from the Aerojet-General Corporation)

ABSTRACT

The surface-to-surface range of a ballistic missile is derived by a simple geometrical method. The errors in range resulting from errors in speed and departure angle are computed by a Taylor series expansion of the range function. Practical considerations are cited which influence the choice of trajectory.

I. INTRODUCTION

THE flight of a ballistic missile is idealized by the assumptions that the speed is acquired impulsively at sea level and that drag is absent. With practical long-range rockets the distance traversed under power is usually 5–10% of the total range, and the length of re-entry path in which drag is significant is even smaller. Consequently the impulsive assumption gives a good first approximation both for the range and for the impact errors of long-range rockets.

II. MAXIMUM BALLISTIC HEIGHT

We first find the maximum height h which is reached by a missile leaving the surface of the Earth vertically with speed u. Equating the initial kinetic energy to the integral of force times distance, we have

$$\tfrac{1}{2}mu^2 = -\int_R^{R+h} mG\,(R/r)^2.dr \quad .. \quad .. \quad (1)$$

where m is the mass of the missile, G is the acceleration of gravity at sea level, R is the Earth's radius and $-G\,R^2/r^2$ is the acceleration of gravity at radius r. Evaluating the integral and solving for h yield

$$\frac{h}{R} = \frac{u^2/2\,GR}{1-(u^2/2\,GR)} \quad .. \quad .. \quad .. \quad (2)$$

Now consider a satellite in a circular orbit at sea level with speed V. The centripetal acceleration is just that of gravity. Hence

$$V^2/R = G, \text{ or } GR = V^2.$$

It is also easily shown that escape speed is $2^{\frac{1}{2}}\,V$. Substitution for GR in (2) gives for the maximum vertical ballistic height h

$$\frac{h}{R} = \frac{(u^2/2V^2)}{1-(u^2/2V^2)} \quad .. \quad .. \quad (3)$$

Note that a missile moving vertically at sea level with speed u equal to satellite speed V will reach a height equal to one Earth radius.

III. THE ELLIPTIC ORBIT

The vertical trajectory we have just considered is a degenerate elliptic orbit with one focus at the centre of the Earth and the other at the apex of the flight. Thus the major axis of the degenerate ellipse is $R + h$. It is shown in many standard references that the major axis of an elliptic orbit depends only on the total energy of the missile.[1,2] Consequently the major axis of the ellipse described by a missile, having speed u at sea level, depends only on u and not at all on the elevation angle θ from the horizontal; in fact the major axis is just $R + h(u)$, where $h(u)$ is given by Equation (3).

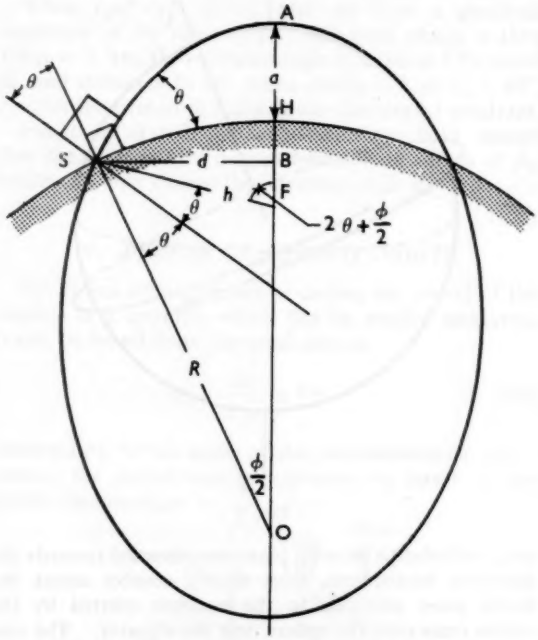

FIG. 1. Ellipse described by ballistic missile

In Fig. 1 an elliptic orbit is depicted with one focus at F. At the starting point S the ellipse makes angle θ with the surface of the Earth. Note that by a well-known property of ellipses $OS + SF$ = major axis = $R + h$. But $OS = R$ so that $SF = h$. A second property of ellipses requires the bisector of $\widehat{OSF}$ to make a right angle with the tangent to the ellipse at S. It follows immediately that the angle $\widehat{OSF} = 2\theta$. Let the range semi-angle $\widehat{BOS}$ be termed $\phi/2$.

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We can now write two equations for the length d of the semichord SB.

$$d = h \sin \{\pi - [2\theta + (\phi/2)]\} = h \sin [2\theta + (\phi/2)]$$
$$= h [\sin 2\theta \cos (\phi/2) + \cos 2\theta \sin (\phi/2)]$$

and $$d = R \sin (\phi/2).$$

Equating these two expressions for d yields

$$\sin [(\phi/2) + 2\theta] = (R/h) \sin (\phi/2) \quad .. \quad (4)$$

and dividing through by cos $(\phi/2)$, we find

$$\tan \frac{\phi}{2} = \frac{\sin 2\theta}{(R/h) - \cos 2\theta} \quad .. \quad .. \quad (5)$$

Eliminating (R/h) with equation (3), we obtain finally

$$\tan \frac{\phi}{2} = \frac{\sin \theta \cos \theta}{(V/u)^2 - \cos^2 \theta} \quad .. \quad .. \quad (6)$$

which gives the range angle ϕ as a function of u and θ. $\phi(u, \theta)$ is presented in Fig. 2. Some practical applications of Equation (6) are made by Allen and Eggers.[3]

IV. THE TRAJECTORY OF MAXIMUM RANGE

If a missile rises vertically with speed u, its range is zero; if it moves horizontally, its range is also zero. For values of θ between $\pi/2$ and 0, with u held constant, the range is greater than zero and reaches a maximum for a particular θ which we call θ_m. The variation of θ with u held constant can be understood by referring to Fig. 1. θ is varied by allowing F to move along the line OA and S to move along the circumference of the circle, remembering that SF has constant length h. It is geometrically evident that the semi-range angle $\phi/2$ will be a maximum, $\phi_m/2$, when F coincides with B, and then

$$\phi_m/2 = \arcsin (h/R), \quad h < R \; .. \quad .. \quad (7)$$

so that the maximum circumferential range $\phi_m R$ is $2R \arcsin (h/R)$. Now the sum of the angles of the triangle OSF is π. When $\phi = \phi_m$, the angle $\widehat{SFO}$ is $\pi/2$, $\widehat{SOF}$ is $\phi_m/2$, and so $\widehat{OSF}$ is $(\pi/2) - (\phi_m/2)$. But $\widehat{OSF}$ is also $2\theta_m$. So the elevation angle θ_m for maximum range with speed u is given by

$$\theta_m = (\pi/4) - (\phi_m/4) \quad .. \quad .. \quad (8)$$

For ranges much less than the radius of the Earth, ϕ is much less than π, so the optimum elevation angle θ_m is just $\pi/4$, which is a familiar result of "flat-Earth" dynamics. When h is much less than R, the maximum range $\phi_m R$ as given by Equation (7) becomes very nearly

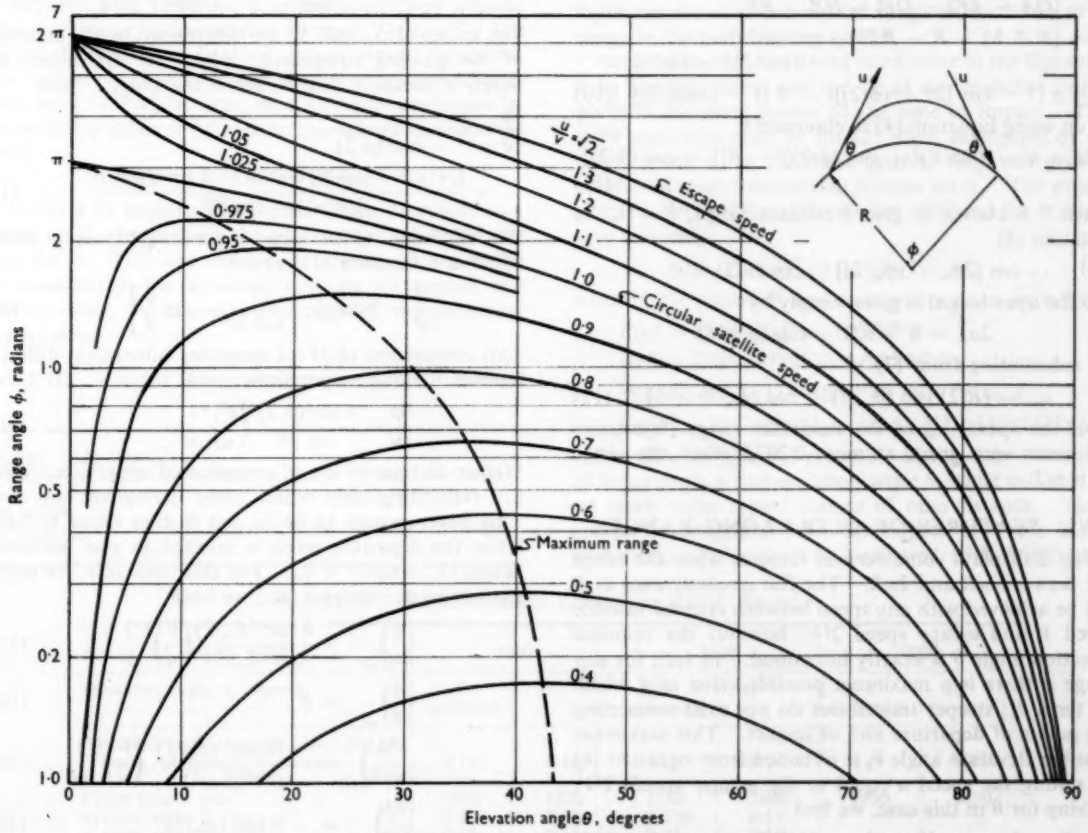


FIG. 2. Dimensionless range of a ballistic missile

$2h$, a second familiar result. We can substitute (3) into (7) to eliminate (h/R); this connects maximum range with sea level speed:

$$\frac{\phi_m}{2} = \arcsin\frac{u^2/2V^2}{1-(u^2/2V^2)} \quad .. \quad .. \quad (9)$$

Equation (8) has shown that at high speeds the maximum range trajectories become very flat, if u is held constant. To a first approximation rockets can be characterized by a constant value of u, independent of the burnout elevation angle θ, as has been verified in a recent article by Culler and Fried.[4] In fact the burnout speed increases slightly with decreasing θ, so that the maximum range trajectories are even flatter than indicated by Equation (8).

Equations (7) and (9) have no solution for $h > R$, *i.e.*, for $u > V$. There is no maximum range for speeds greater than satellite speed. The disappearance of the maximum is illustrated in Fig. 2 at the point $\phi = \pi$, $\theta = 0$.

V. APEX HEIGHT OF THE TRAJECTORY

The apex height a can be found in terms of h and ϕ from the relation

$$\begin{aligned} 2a &= (OA + AF) - OH - HB - BF \\ &= (R+h) - R - R\,[1-\cos(\phi/2)] - \\ &\qquad -h\cos[2\theta+(\phi/2)] \\ &= h\,\{1-\cos[2\theta+(\phi/2)]\} - R\,[1-\cos(\phi/2)] \quad (10) \end{aligned}$$

or, on using Equation (4) to eliminate θ,

$$2a = h - R[(h/R)^2 - \sin^2(\phi/2)]^{\frac{1}{2}} - R[1-\cos(\phi/2)] \quad .. \quad (11)$$

When θ is chosen to give maximum range, $\theta = \theta_m$, in equation (8)

$$\cos[2\theta_m + (\phi_m/2)] = \cos(\pi/2) = 0$$

and the apex height is given simply by

$$2a_m = h - R[1-\cos(\phi_m/2)]$$

or, substituting from (7)

$$a_m = (R/2)\,[\sin(\phi_m/2) + \cos(\phi_m/2) - 1] \quad (12)$$

Thus the apexes a_m of the maximum range trajectories are never very great, at most $0{\cdot}207R$ when the range ϕ_m is $\pi/2$.

VI. FEATURES OF ULTRA-LONG RANGES

Fig. 2 displays some curious features when the range lies between πR and $2\pi R$. The full circumference $2\pi R$ can be achieved with any speed between circular satellite speed V and escape speed $2^{\frac{1}{2}}V$; however the required elevation angle θ is exactly horizontal. In fact, for any range ϕ there is a maximum possible value of θ which we term θ_s; steeper trajectories do not exist connecting the points of departure and of impact. This maximum possible elevation angle θ_s is obtained from equation (6) by setting the speed u equal to the escape speed, $2^{\frac{1}{2}}V$. Solving for θ in this case, we find

$$\theta_s = \tfrac{1}{2}\arctan\{\tfrac{1}{2}\tan[\pi - (\phi/2)]\} \quad .. \quad .. \quad (13)$$

This function has odd symmetry about $\theta_s = \pi/4$, $\phi = \pi$, and a few values are given in Table I. Since ranges ϕ greater than 90° of arc (6220 miles) will seldom be required, one can see that with a sufficient propulsive system very steep trajectories are attainable, and they present some obvious military advantages.

TABLE I.—*Steepest Angle of Elevation, θ_s.*

ϕR, miles	θ_s, degrees
0	90
6220	76·7
12440	45·0
18660	13·3
24880	0

VII. RANGE ERRORS

From Equation (6) we have

$$\phi(u,\theta) = 2\arctan\frac{\sin\theta\cos\theta}{(V/u)^2 - \cos^2\theta} \quad .. \quad (14)$$

The range error $\Delta\phi$ due to errors Δu and $\Delta\theta$ is obtained most easily by expanding ϕ in Taylor series

$$\Delta\phi = \frac{\partial\phi}{\partial u}\Delta u + \frac{\partial\phi}{\partial\theta}\Delta\theta + \frac{1}{2!}\left[\frac{\partial^2\phi}{\partial u^2}(\Delta u)^2 + \right.$$
$$\left. + \frac{2\partial^2\phi}{\partial u\partial\theta}\Delta\theta\,\Delta u + \frac{\partial^2\phi}{\partial\theta^2}(\Delta\theta)^2\right] + \ldots \quad (15)$$

The values of Δu and $\Delta\theta$ are determined by the accuracy of the guiding equipment,[5] while the derivatives are purely a function of the chosen trajectory. Now

$$\frac{\partial\phi}{\partial\theta} = \frac{2}{1+\tan^2(\phi/2)} \times$$
$$\times \frac{[(V/u)^2 - \cos^2\theta]\cos 2\theta - 2\sin^2\theta\cos^2\theta}{[(V/u)^2 - \cos^2\theta]^2} \quad .. \quad (16)$$

We eliminate (V/u) with Equation (14) and obtain $\partial\phi/\partial\theta$ as a function of ϕ and θ.

$$\frac{\partial\phi}{\partial\theta} = 2\sin\phi\,.\left[\frac{1}{\tan 2\theta} - \tan\frac{\phi}{2}\right] \quad .. \quad (17)$$

This elimination of (V/u) simplifies subsequent differentiations. Similar operations yield

$$\frac{\partial\phi}{\partial u} = \frac{8\sin^2(\phi/2)}{\sin 2\theta}\left(\frac{V}{u}\right)^2\frac{1}{u} \quad .. \quad .. \quad (18)$$

Higher derivatives are of complicated apperance. They are interesting only when lower derivatives are zero. This never occurs to $\partial\phi/\partial u$, but it does occur to $\partial\phi/\partial\theta$ when the departure angle is selected to give maximum range, *i.e.*, when $\theta = \theta_m$. For this value of θ, the higher derivatives are simpler, and we have

$$\left.\frac{\partial\phi}{\partial u}\right)_m = \frac{8\sin^2(\phi_m/2)}{\cos(\phi_m/2)}\left(\frac{V}{u}\right)^2\frac{1}{u} \quad .. \quad (17A)$$

$$\left.\frac{\partial\phi}{\partial\theta}\right)_m = 0 \quad .. \quad .. \quad .. \quad .. \quad (18A)$$

$$\left.\frac{\partial^2\phi}{\partial u\partial\theta}\right)_m = \frac{-16\sin^3(\phi_m/2)}{\cos^2(\phi_m/2)}\left(\frac{V}{u}\right)^2\frac{1}{u} \quad .. \quad (19A)$$

$$\left.\frac{\partial^2\phi}{\partial\theta^2}\right)_m = -8\tan(\phi_m/2) \quad .. \quad .. \quad (20A)$$

TABLE II.—*Range Errors Resulting from Errors in Speed and Elevation Angle*

Range, ϕR, statute miles	3000		5000		7000	
Elevation angle, θ, degrees	34·1 optimum	45	26·9 optimum	45	19·7 optimum	45
Speed, u, ft./sec.	19100	19650	22300	23900	24200	27500
$R\frac{\partial\phi}{\partial u}$, $\frac{\text{miles}}{\text{ft./sec.}}$	0·445	0·380	0·830	0·542	1·41	0·609
$R\frac{\partial\phi}{\partial\theta}$, $\frac{\text{miles}}{\text{millirad.}}$	0	−2·11	0	−5·51	0	−9·32
$R\frac{\partial^2\phi}{\partial u\,\partial\theta}$, $\frac{\text{miles}}{\text{(ft./sec.)-millirad.}}$	$-0{\cdot}352\times10^{-3}$	—	$-1{\cdot}21\times10^{-3}$	—	$-3{\cdot}38\times10^{-3}$	—
$\frac{\partial^2\phi}{\partial\theta^2}$, $\frac{\text{miles}}{\text{(millirad.)}^2}$	−0·0126	—	−0·0232	—	−0·0380	—

In Table II we show some typical values of $\partial\phi/\partial\theta$ and of $\partial\phi/\partial u$, computed from equations (17) through (20A) and from Fig. 2, and it is noteworthy that $\partial\phi/\partial u$ becomes very large at long ranges and small elevation angles θ. In fact this dependence of ϕ on u is inconveniently strong in terms of present-day guidance technology. By using larger elevation angles θ, one can considerably reduce $\partial\phi/\partial u$ and hence the range error; however, greater speed is required and therefore a larger propulsion system. This technique is sometimes termed "lofting." The second derivatives in Table II appear almost negligible. The values of $R\partial\phi/\partial\theta$ should not be compared directly with those of $R\partial\phi/\partial u$, since each has to be multiplied by the probable value of $\Delta\theta$ and Δu to estimate the resulting error.

VIII. LATERAL ERROR

An error in departure azimuthal angle $\Delta\epsilon$ results in a lateral displacement Δx in the impact point, of magnitude $R\Delta\epsilon \sin\phi$. This can readily be shown geometrically by considering the spherical triangle containing the starting point, the intended impact point and the actual impact point.

TABLE III.—*Lateral Impact Errors Induced by Azimuthal Error*

Range, ϕR, statute miles	3000	5000	7000	9000
$\frac{\Delta x,\ \text{miles}}{\Delta\epsilon\ \text{millirad.}}$	2·72	3·76	3·88	3·02

IX. ERRORS DUE TO EARTH ROTATION

In the preceding analysis the effect of terrestrial rotation was ignored. The range-angle, ϕ, was computed in a stationary system. If the vector u, θ incorporates the velocity of the launch point, the preceding results can be applied to the rotating Earth. However, the range ϕ is still computed in the fixed system. It is a simple matter to calculate the motion of the target during the time of flight and hence to convert the range on the Earth to the range in the non-rotating system.

An error in u or θ will lead to an error in the flight time t, so that the target will not be at the predicted impact point in the fixed system at the time of impact. Thus $\partial t/\partial\theta$ and $\partial t/\partial u$ must be found; when multiplied by the target speed u_t in the fixed system, they will give an additional miss-distance due to time error. The expressions for time of flight[6] $t(u, \theta)$, for $\partial t/\partial u$ and for $\partial t/\partial\theta$ are very unwieldy.

$$t(u, \theta) = (P/\pi)\,(\arcsin f - ef) \qquad (21)$$

where f, the period P, and eccentricity e are given by

$$P(u) = (2\pi R/V)\,[1 + (h/R)]^{3/2}$$

$$h(u) = R(u^2/2V^2)\,[1 - (u^2/2V^2)]^{-1}$$

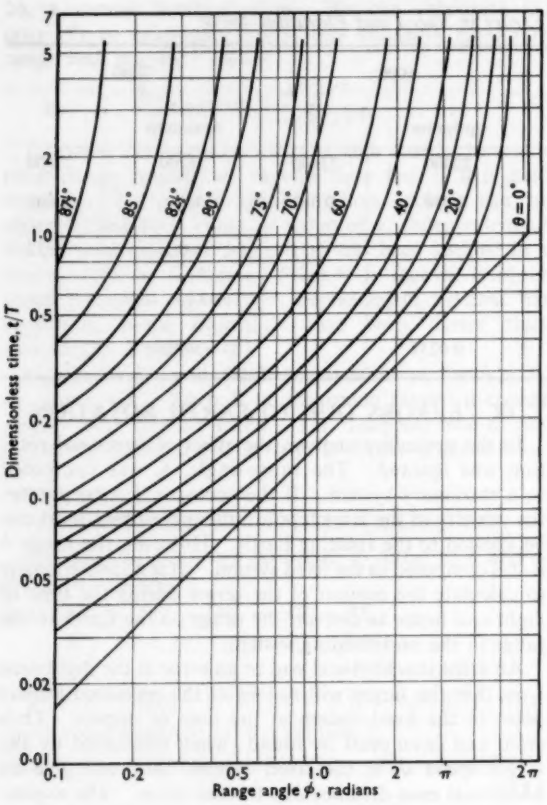
$$e^2(u, \theta) = 1 - [2 - (u^2/V^2)]\,(u^2/V^2)\cos^2\theta$$

$$f(u, \theta) = (1 - e^2)^{\frac{1}{2}}\,[1 - e\cos(\phi/2)]^{-1}\sin(\phi/2).$$

The time of flight t is presented in Fig. 3 as a function of range angle ϕ and elevation angle θ, while in Table IV we show some typical values of miss-distance. These are to be compared with the entries in Table II; in particular, $u_t\partial t/\partial u$ is to be compared with $R\partial\phi/\partial u$ and

TABLE IV.—*Miss Distances Caused by Earth Rotation*

Range, ϕR, statute miles	3000		5000		7000	
Elevation angle, θ, degrees	34·1 optimum	45	26·9 optimum	45	19·7 optimum	45
Assumed typical target speed due to Earth rotation u_t, miles/sec.	0·14	0·14	0·14	0·14	0·14	0·14
Flight time t, sec.	1050	1520	1680	2660	1950	4790
$u_t\,\partial t/\partial u$, miles/ft./sec.	0·021	0·038	0·076	0·13		
$u_t\,\partial t/\partial\theta$, miles/millirad	0·16	0·15	0·27	0·16		



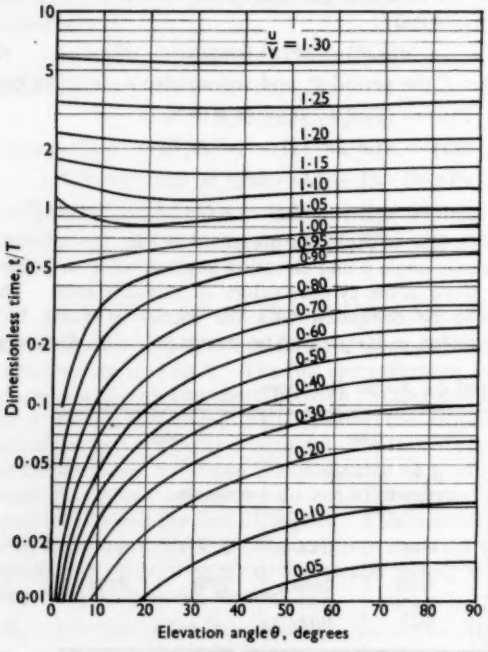


FIG. 3. Dimensionless time of flight of a ballistic missile.

$u_t \partial t/\partial\theta$ with $R\partial\phi/\partial\theta$. Usually the miss-distance caused by Earth rotation will be less than the fixed system miss-distances of Table II. Thus the Earth rotation errors are usually small but not unnoticeable. But when the speed of the rocket is very near escape speed and when lofting trajectories are used, the Earth rotation miss-distances can become predominant. In extreme cases the Earth rotates many times before the rocket lands.

X. CONCLUSION

The range and accuracy of long-range ballistic missiles have been approximately computed in terms of the initial velocity vector and errors in the initial velocity vector. The calculations are too crude for the compilation of range tables, but they will suffice for overall system comparisons. Some important perturbing factors excluded from consideration were oblateness of the Earth,[7,8] local irregularities of gravity near the launch site, and the precise shape of the powered trajectory[4] and re-entry path[9].

ACKNOWLEDGEMENT

I wish to thank the Aerojet-General Corporation for the use of its IBM 704 to compute Fig. 3.

LIST OF SYMBOLS

- a apex height.
- A apex point of trajectory.
- B midpoint of chord.
- d length of semi-chord.
- e eccentricity.
- f a function of u and θ.
- F second focus of ellipse.
- G acceleration due to gravity at sea level.
- h vertically attainable ballistic height with speed u.
- m mass of missile.
- O centre of the Earth.
- P period of ellipse.
- R radius of the Earth.
- S starting point of missile.
- t time of flight.
- T period of satellite at sea level.
- u starting speed of missile in non-rotating system.
- u_t target speed in non-rotating system.
- V circular satellite speed at sea level.
- ϵ azimuthal angle of departure in non-rotating system
- θ elevation angle of departure in non-rotating system.
- ϕ range angle in non-rotating system.

Subscripts:

- m maximum range trajectory.
- s steepest trajectory.

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ACCURACY REQUIRED FOR A RETURN FROM INTERPLANETARY VOYAGES*

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(Communication from Aeronutronic Systems, Inc.)

ABSTRACT

The navigational accuracy required for the application of braking-ellipse techniques to a return from interplanetary voyages is discussed. It is determined that a large portion of the total aerodynamic heating and drag during the braking-ellipse manoeuvre is encountered in the transitional aerodynamic-regime between free-molecule-flow and continuum-flow. In the case of re-entry from a ballistic orbit, on the return leg of a round trip to Venus, the target at the Earth is found to be a thin circular annulus. Results of computations, obtained by the employment of a drag-perturbation technique, indicate that the radius of the annulus would be 4·64 Earth radii and that for a vehicle having a mass/area quotient of 5 g./cm.² and with no special cooling devices, its width would be only 7 km. Such stringent accuracy requirements suggest the employment of small auxiliary retro-rockets to "steer" the vehicle into the correct atmospheric level after circling the Earth once. The accuracy required for braking-ellipse landings on Mars and Venus are also mentioned.‡

I. INTRODUCTION

THE problems associated with re-entry from space orbits is somewhat different from the re-entry problem involved in IRBM, ICBM, glider, and satellite vehicles. Essentially, the space vehicle returning from the Moon or planets will approach the Earth at speeds in excess of the geocentric parabolic speed (*i.e.*, in excess of 11·18 km./sec.). At these higher speeds, the re-entry phenomena border on those of meteoritics. Furthermore, we can expect that "braking-ellipses" and possibly "skipping" techniques, which were proposed by astronauts many years ago, will be employed (braking ellipses would not, perhaps, be useful in the low-thrust re-entry of non-ballistic trajectories; see Fig. 1).§ The braking ellipses would be advantageous in that they could remove over half of the kinetic energy of the space vehicle before final re-entry. To remove this energy by either special cooling devices or a "retro-rocket" would involve excessive weight penalties; *e.g.*, if the exhaust speed were 2 km./sec., then 80% of the mass of the re-entry vehicle would have to be propellent, and even if the exhaust speed were 3·5 km./sec. (theoretically, the maximum value for chemical propellents) then 60% of the mass of the vehicle would be propellent.**

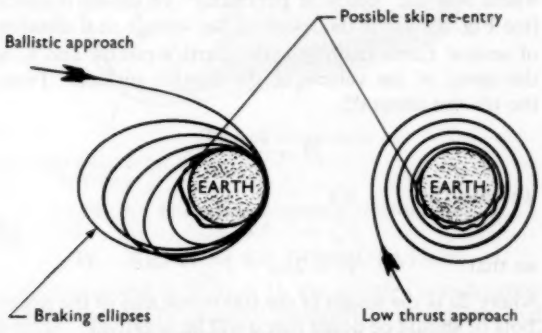

FIG. 1. High-speed re-entry techniques

II. AERODYNAMIC REGIME OF FLOW

In order to determine the aerodynamic drag and heat-transfer encountered during the braking-ellipse landing, it is necessary to ascertain the regime of flow. Let us roughly estimate the altitude where aerodynamic heating will exceed radiative cooling.

If Λ is the heat-transfer coefficient (equal to unity in the free-molecule-flow regime), then

$$\frac{\text{Aerodynamic Heating}}{\text{Radiative Cooling}} = \frac{\Lambda\rho\dot{y}^3}{2\epsilon_s\sigma_s(T_s^4 - T_0^4)} \quad \ldots \quad (1)$$

where ρ = the atmospheric density, $\dot{y}$ = the vehicle's speed, ϵ_s = the emissivity of the surface, σ_s = the Stefan constant, T_s = the surface temperature, and T_0 = the equilibrium temperature. For this ratio to be unity at a re-entry speed of 10 km./sec. and with a surface temperature of 1000° K.,

$$\rho = 10^{-10}\ \text{g./cm}^3.,$$

which corresponds to an altitude of 112 km., where the mean-free-path is about 6 metres. Furthermore, on the assumption that the re-entry vehicle had a mass/area quotient of 5 g./cm.² (or a "weight/drag ratio" of 2·5 to 5·5, depending upon the drag coefficient, C_D, which would correspond to a light drag canopy or to a balloon), it would undergo a drag deceleration of 1 g at

$$\rho = 5 \times 10^{-9}\ \text{g./cm.},$$

which corresponds to an altitude of 86 km., where the

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‡ *Note added in proof.* Applications of these same principles have been made by the author to meteoritic encounter, in his paper[11] "Ephemeral Natural Satellites of the Earth."

§ Solar and drag perturbations cause rotation of apsides.

** $\frac{m}{m - m_p} = \exp \Delta\dot{y}/c$, where $\Delta\dot{y}$ = the decrease in speed (*e.g.*, $\Delta\dot{y} = 11 - 8 = 3$ km./sec.), m = the mass of the vehicle, m_p = the mass of the propellent, and c is the exhaust speed of the propellent.

mean-free-path is about 1 cm.; consequently, high-speed, re-entry aerodynamic phenomena, during the braking ellipses, will probably involve low-drag accelerations (to avoid excessive aerodynamic heating) and will occur primarily in the transitional and slip-flow-regimes[1]. Fig. 2 indicates the deceleration (in g's) and the variation of the transitional parameter* B (or the inverse of the modified Knudsen number, *i.e.*, $1/Kn$) as a function of vehicle altitude and speed, and verifies the fact that the flow will not be a continuum one. No account, however, has been taken of heat conduction into a heat sink, sublimation, pyrolysis, etc. Certainly, as it has been determined by Carl Gazley, Jnr.,[2] these cooling devices would allow a deeper penetration into the atmosphere and, at least near perigee, the aerodynamic phenomena would be primarily in the continuum regime. But since the application of such cooling devices has not proven necessary for the accomplishment of a reasonable braking-ellipse landing, they have not been included in the computations of this paper (even if a deeper penetration were possible, it is probable that a large portion of the drag and heat transfer would still occur in the transitional regime).

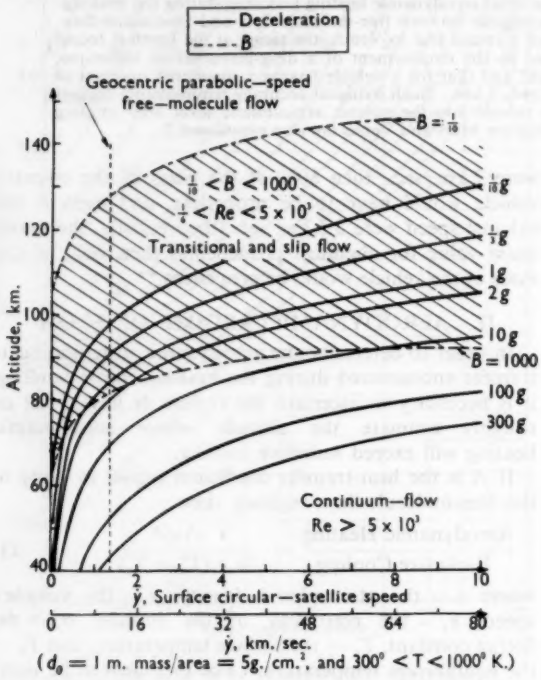

FIG. 2. Typical re-entry drag canopy deceleration

In the case of low-thrust (*e.g.*, ion, plasma, or fusion propulsion) trajectories, the atmosphere would still present a formidable problem. In this case, we can assume that the orbit will initially be made nearly circular by properly directing the propulsive device. Typically, such unconventional propulsion schemes would involve thrust forces of 10^5 to 10^6 dynes. If we assume that the frontal area of the re-entry vehicle is 10^4 to 10^5 cm.^{2}, then the thrust force will be equal to the drag force at

$$\rho = 10^{-11} \text{ g./cm.}^3.$$

This density corresponds to an altitude of about 132 km., which also is in the transitional regime, but the vehicle is at this altitude only briefly. During the re-entry of such a low-thrust vehicle, the judicious employment of thrust and possibly lift—based upon accurate navigation—will be necessary for proper recovery; however, no examples of low-thrust return will be presented in this paper.

III. RE-ENTRY FROM BALLISTIC ORBITS

In the case of an approach to the Earth along a ballistic orbit, the vehicle will move on a geocentric hyperbolic orbit as shown in Fig. 3. The Earth will assume varying degrees of affinity for the vehicle, which will depend upon the relative speed of approach. The affinity can be expressed in terms of an effective, gravitational cross-section.† The radius of this cross-section is easily derived from the principle of the conservation of angular momentum and from the *vis viva* integral.‡ Equating the angular momentum, $b\dot{y}_\infty$, at a point a great distance from the Earth to that at its surface, we find that

$$b\dot{y}_\infty = r_0\dot{y}_e \quad .. \quad .. \quad .. \quad (2)$$

where b is the "collision parameter" or off-set distance (see Fig. 3), $\dot{y}_\infty$ is the speed of the vehicle at a distance of several Earth radii, r_0 is the Earth's radius, and $\dot{y}_e$ is the speed of the vehicle at the Earth's surface. From the *vis viva* integral‡

$$\dot{y}^2 = \frac{2}{r} - \frac{1}{a},$$

we have (for $r \to \infty$)

$$\dot{y}_\infty^2 = -1/a, \quad .. \quad .. \quad .. \quad (3)$$

so that

$$\dot{y}_e^2 = 2/r_0 + \dot{y}_\infty^2,$$

where $2a$ is the length of the transverse axis of the hyperbola (it should be noted that a will be negative). Solving for b (the radius of the effective, gravitational cross-section), we obtain

$$b = r_0\,[1 + (2/\dot{y}_\infty^2 r_0)]^{\frac{1}{2}} \quad .. \quad (4)$$

Let us consider as an example a return trip to Earth from Venus, for which $\dot{y}_\infty = 0{\cdot}316$ times the surface circular-satellite speed (*i.e.*, $0{\cdot}316 \times 11{\cdot}18$ km./sec.) and $b = 4{\cdot}64$ Earth radii. This effective cross-section

* The transitional parameter, B, represents the ratio of a characteristic length to the mean-free-path of a molecule re-emitted from the re-entry body's surface with respect to the oncoming molecules; *cf.* Reference (1).

† See Chapter 8 of Reference 7.

‡ The *vis viva* or energy "integral" is simply a conservation of energy equation in which $\dot{y}^2$ represents the kinetic energy, $-2/r$ the potential energy, and $-1/a$ their constant sum.

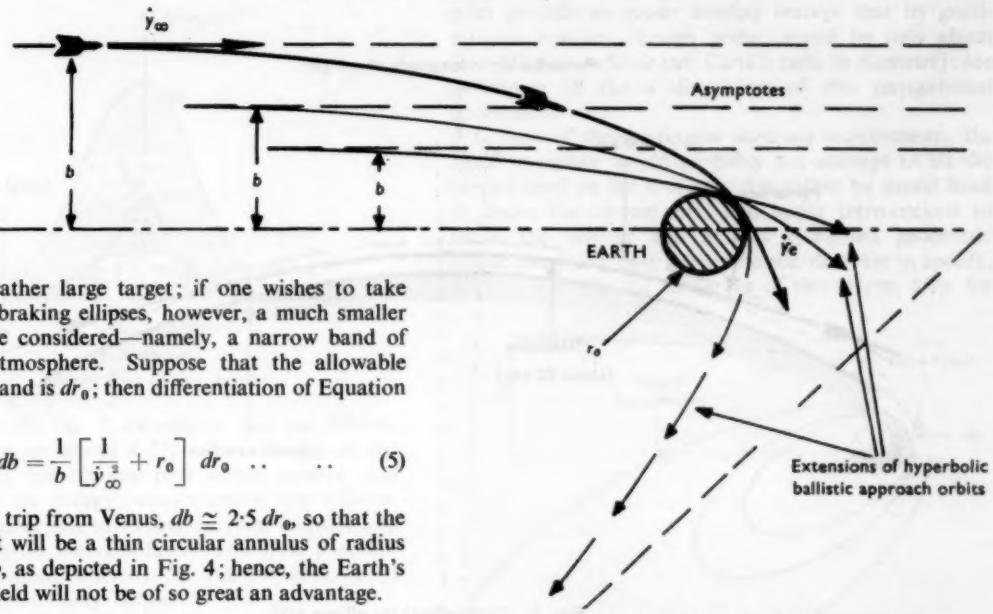

FIG. 3. Hyperbolic ballistic approach orbits

represents a rather large target; if one wishes to take advantage of braking ellipses, however, a much smaller target must be considered—namely, a narrow band of the Earth's atmosphere. Suppose that the allowable width of this band is dr_0; then differentiation of Equation (4) will yield

$$db = \frac{1}{b}\left[\frac{1}{\dot{y}_\infty^2} + r_0\right] dr_0 \quad .. \quad .. \quad (5)$$

For the return trip from Venus, $db \cong 2{\cdot}5\, dr_0$, so that the effective target will be a thin circular annulus of radius b and width db, as depicted in Fig. 4; hence, the Earth's gravitational field will not be of so great an advantage.

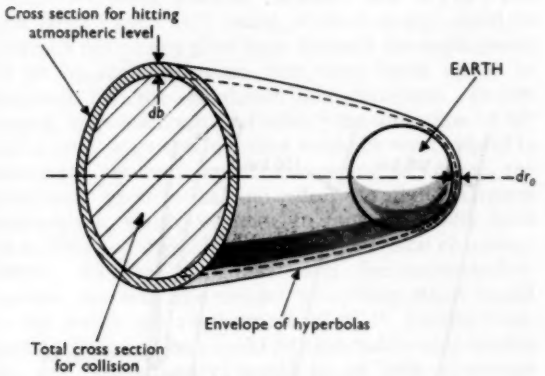

FIG. 4. Effective gravitational cross-section

IV. RESULTS OF COMPUTATION

As was noted in Section II, the re-entry aerodynamic phenomena will be centered primarily in the transitional regime; accordingly, certain aspects of the drag, and heat-transfer phenomena, already formulated for meteorites, can be carried over directly to the problems of high-speed re-entry (see, *e.g.*, Reference 3).

Fig. 5 illustrates a typical braking elliptical orbit near perigee (the perturbation in longitude of the perigee, $\triangle\tilde{\omega}$, should be noted) calculated with a drag-perturbational technique developed elsewhere.* Fig. 6 shows a plot of vehicle speed as a function of altitude for a number of gravity-free perigee distances for bodies re-entering with parabolic speed (*i.e.*, coming in with an initial speed of zero from infinity).

It should be noted from Fig. 6 that, although the dynamic pressure, P, remains very low, the surface temperature, T_s, becomes prohibitively high near the true perigee of the 105-km. case (heat transfer into the vehicle has not, however, been considered. In this regard, the reader's attention is directed to a treatment of the heating problem by Carl Gazley[2]). For this 105-km., gravity-free, perigee case, the final speed of 10·819 km./sec. at 130 km. would lead to a geocentric ellipse, whose semi major axis would be about 11·5 Earth radii, whereas, for the 108-km. case, the final speed would be 10·979 km./sec. at a height of 130 km., and an ellipse with a semi-major-axis of 32·2 Earth radii would result.† The latter ellipse would be strongly affected by both solar and lunar perturbations, which would tend to decrease the perigee distance, and thus render the orbit undesirable. On the one hand, then, the vehicle moving on a braking ellipse would be limited by high temperatures if too large a reduction should occur in its speed, and, on the other hand, it would be limited by solar and lunar perturbations if too small a reduction were made; furthermore, a small reduction in speed would require a large number of passes to retard

* References 3 and 6. And see Reference 8 for an alternate integration scheme.

† $\frac{1}{a} = \dot{y}_p^2 - \dot{y}_f^2$, where $\dot{y}_p$ = the initial entry parabolic speed, and $\dot{y}_f$ = the final exit speed—both expressed in units of the surface, circular-satellite speed.

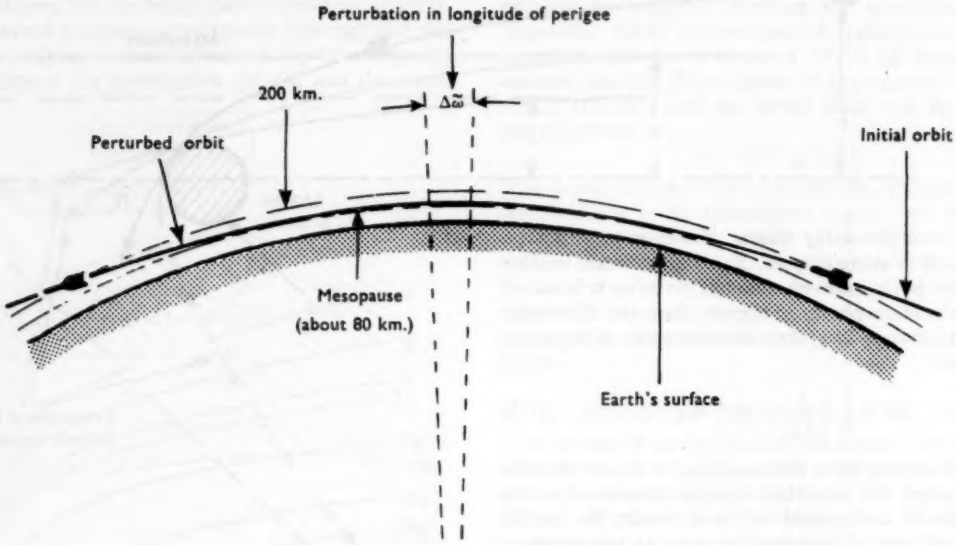

FIG. 5. Typical braking-ellipse orbit

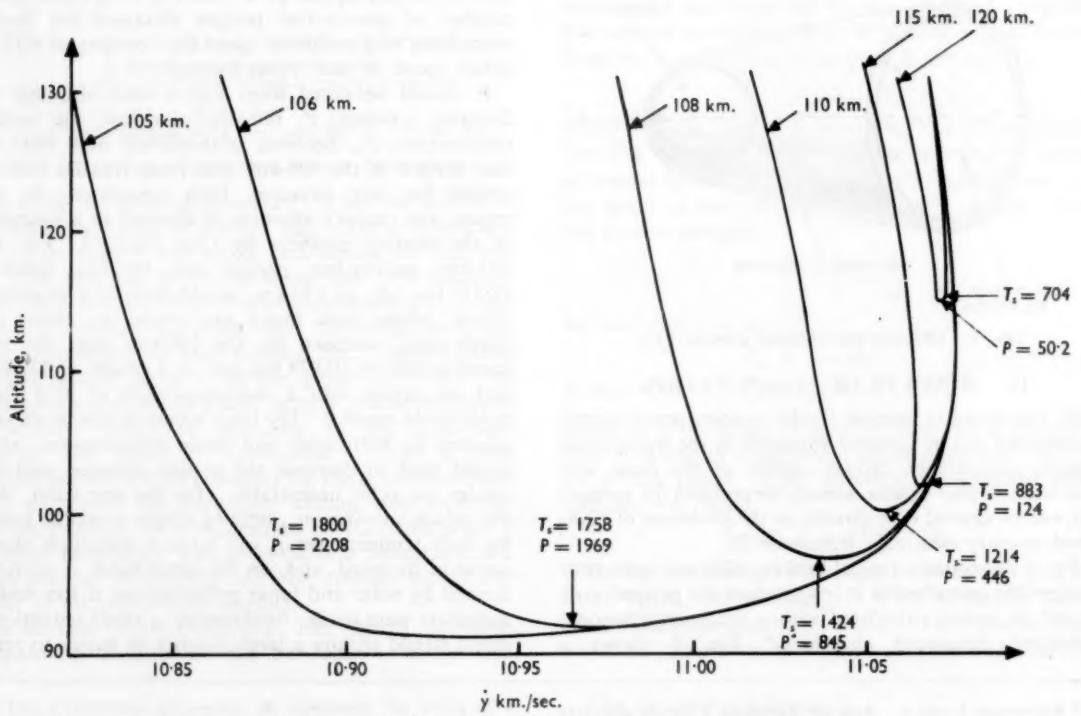

FIG. 6. High-speed re-entry drag canopy for various gravity-free perigee distances

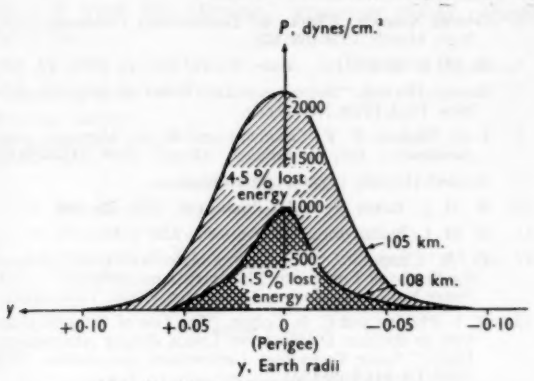

FIG. 7. Energy loss during a pass

the vehicle. From Fig. 7, we observe that the 105-km. pass would remove about 4·5% of the energy of the vehicle, whereas the 108-km. pass would remove only about 1·5% of its energy; consequently, the 105-km. case would require ten to twenty braking ellipses, and these would extend the retardation time over a period of a month or more, whereas, the 108-km. case would require more than thirty ellipses.*

The foregoing analysis indicates that $dr_0 \cong 3$ km. and $db \cong 7$ km.† Of course, if more energy could be given up during any given pass, through the employment of lift or cooling devices, then these limits would be increased and the retardation time decreased. In this regard, as pointed out by Gazley,[2] the utilization of lift and a small mass/area quotient would be most helpful in decreasing the heat transfer (according to Gazley, the mass/area quotient has no effect on the maximum deceleration, which, without lift, ranges typically from 8g to 326g and depends only upon the orbital characteristics)‡. In the transitional and free-molecule-flow regimes, however, the meager lift-to-drag ratios would hardly justify the employment of lift.[15] Furthermore, cooling devices at best could be expected to only double dr_0, and, consequently, would be of little advantage in so far as the navigational aspects of the problem are concerned. On the other hand, such cooling mechanisms could considerably increase the energy given up at each pass and, hence, shorten the retardation time and decrease the effect of solar perturbations.

Although the results of this paper are only strictly valid with respect to the Earth's atmosphere, the results for Venus should be quite similar and, as pointed out by Samuel Herrick,[9] the Martian atmosphere should even provide an easier landing (except that its gravitational annulus, though wider, would be only about four Martian radii or two Earth's radii in diameter); see Reference 10 for a discussion of this navigational problem.

In view of these stringent accuracy requirements, the space navigator would probably not attempt to hit the correct level on the first pass, but rather he would head in above the correct level and apply retro-rockets to brake the vehicle into a very elongated geocentric ellipse (requiring only a 0·3 mile/sec. decrease in speed); see Fig. 8.§ On the return leg of this ellipse, after the

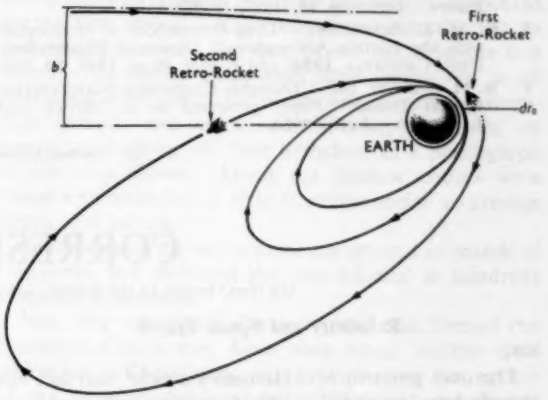

FIG. 8. Braking-ellipse manoeuvre

vehicle was relatively free of solar and lunar perturbations and after its orbit was accurately determined, a second small retro-rocket would modify the orbit so as to pass precisely through the correct level.[4] In this way, the more efficient employment of thrust near apogee has been traded for a more precisely determined orbit near the Earth.

ACKNOWLEDGEMENTS

Several years ago, Professor Samuel Herrick of the Department of Astronomy of the University of California, Los Angeles, suggested the study of those parts of celestial mechanics and aerodynamics partially represented in this paper. Since then, he has given me many helpful suggestions, especially in regard to perturbation techniques. Professor Andrew F. Charwat of the Department of Engineering inspired my investigation of transitional aerodynamic drag and contributed significantly to its theory.

* Each pass removes approximately the same amount of energy since the reduction in the speed of the vehicle is compensated by a gradual decrease in the altitude of perigee (causing the vehicle to pass through successively lower and denser atmosphere).

† *Note added in proof.* A similar analysis, carried out by George Xenakis[5] indicated that $dr_0 < 15$ km. The difference between the calculations appears to result from the employment of a different heat-transfer-coefficient variation and different temperature and perturbation limitations.

‡ There is disagreement on the advantages of employing lift.[12, 13] Lift may not require braking ellipses and initial accuracy requirements are not as severe. Nevertheless, lift adds a complication to the design and, hence, decreases reliability; adds extra weight and increases the total heat input to the vehicle unless a complicated variable lift programme is employed.[14] Consequently, both lift and non-lift vehicles will probably be utilized.

§ It should be noted that the firing of the first retro-rocket would probably be preceded by a small corrective thrust fired while the vehicle was still several Earth radii out from the Earth; such a correction would assure that the vehicle would, indeed, miss the Earth.

I gratefully acknowledge the assistance of Dr. Eric Durand of Aeronutronic Systems, Inc., who made possible the early completion of this paper by allowing me to utilize the Aeronutronic computer and by sponsoring much of my research. Mrs. Elsie Browne, also of Aeronutronic Systems, Inc., gave me invaluable aid in programming my computations on the IBM 650 computer.

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CORRESPONDENCE

(In these letters to the Editor, some passages have necessarily been omitted)

Relativity and Space Travel

SIR,

The only point in Mr. Herman's article[1] that has not already been answered in this discussion is his explanation of the slowing down in terms of a gravitational field created by the traveller on accelerating (p. 566). This explanation was first given qualitatively by Einstein[2], and later treated quantitatively (but only to a first approximation) by various writers. The latest account is that of Born and Biem[3], and this, surprisingly, was its first appearance in connection with the present phase of this old controversy. I submitted a reply, but the communicator of Born and Biem's paper refused to communicate it to the Amsterdam Academy on the strange ground that I had already had sufficient opportunity to answer the argument before it had appeared: he offered no criticism of my reply. I will not here attempt a full analysis but merely give one reason why the argument cannot be maintained.

The essential point of the argument is that if the traveller's clock, M, is supposed to remain at rest, a gravitational field must be supposed to appear (some may object to Mr. Herman's statement that M creates it, but that is immaterial) whenever M's engine operates. This keeps clock M at rest but makes clock R move since it has no counteracting engine. The effect of these fields on the clocks is therefore a part of the problem. Three such fields appear—when M starts out, when it reverses, and when it stops on return. On the first and last of these occasions M and R are affected equally because they are at the same place, but on the second they are far apart, and their difference of gravitational potential retards M relatively to R by an amount which overpowers the relative slowing down of R owing to its uniform motion between the accelerations (Mr. Herman does not mention the initial and final fields, but Einstein and the others do, and they are obviously involved to the same extent as the intermediate field). The result is that on reunion M is behind R by the same amount as that calculated on the assumption that it is M and not R which moves.

The following consideration shows that this explanation cannot be accepted. Suppose that on α Centauri (practically stationary with respect to the Earth) there is a third clock, R', which is synchronized with R by light signals in the usual way. Then there is never any relative motion between R and R', so their relative rates cannot change on account of motion. For simplicity, let us suppose that R and R' are synchronized after M has begun its journey, so that no question arises about the effect on R' of M's initial acceleration. Then, when M reaches α Centauri it is at the same place as R', so M and R' must be equally affected by the gravitational field accompanying M's reversal; therefore, both equally show a rapid retardation with respect to R. R, therefore, who is observing R' continuously, sees it suddenly go slow— in Sir George Thomson's example by some five years, which somehow has to be accomplished during the short time of M's reversal.

This should be sufficient to show that these relativity "effects" are coordinate effects, not physical changes in clocks. But if there is to be an observable difference between R and M when they reunite, they must be such physical changes; you cannot suppose the process purely conceptual until you come to the end, and then suddenly make its result a fact of observation.

That is what Mr. Herman's argument would compel us to do.

HERBERT DINGLE.

104, Downs Court Road,
Purley, Surrey.

26 February, 1959.

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Meteor Craters

SIR,

In a recent Technical Review[1], E. T. B. Smith quotes Wyatt as making the suggestion[2] that some of the larger meteor craters can be explained on the assumption that anti-terrene matter caused the "almost inconceivable" damage.

There is no need to postulate any such anti-terrene matter. Both the case of the Tunguska meteorite of 1908 and the Barringer Crater of Arizona, observational evidence of which the writer has extensively studied, can be fully accounted for by the impact of a meterorite of reasonable size.

In the case of the Tunguska meteorite, it is apparent from eye-witness reports from a distance and from the layout of fallen trees that the meteor hit the Earth with a large velocity on its advancing hemisphere, *i.e.*, it had a retrograde orbit, so that it evaporated so completely during the explosion caused by its collision that no fragments were left on the ground.

Some possible figures for the size and mass of the object can be given on the assumption that all of the meteoritic material evaporated, together with an appreciable amount of soil and rock.

The amount of heat required to vaporize a mixture of water, soil, rock and meteoritic material would be about 1000 cal./g. For a violent explosion, consuming energy in chemical decomposition, about 10,000 cal./g. would be needed.

From the appearance of the meteorite as a brilliant fireball in daylight from hundreds of miles away, and the fact that its heat was felt at a distance of 50 miles, it has been calculated that the velocity at impact was about 60 km./sec. Its mass has been estimated[3] at more than a million tons. Since 1 ton is roughly 10^6 g., the kinetic energy ($\frac{1}{2}mv^2$) is therefore $1{\cdot}8 \times 10^{25}$ ergs, the equivalent of $4{\cdot}5 \times 10^{17}$ calories (it has been computed that the San Francisco earthquake of 1906 released 10^{27} ergs). The Siberian meteorite could therefore have exploded $(4{\cdot}5 \times 10^{17})/10^4 = 4{\cdot}5 \times 10^{13}$ g., or fifty times the mass of the original body.

Let us now suppose that only 1% of the energy is spent in lifting the material; the latter would then have a value of 2×10^{16} g. That is on the assumption that the Tunguska meterorite impact could lift a million times its own mass (or 10^{18} g. of material) to an average height of 100 metres. The result is too large, for energy is also expended in shattering the terrestrial rocks, pushing them sideways, and in producing earthquake waves.

With an average density of 3 g./cm.^{3} (about equal to that of surface rocks), the volume of the excavated material would be 7×10^{15} cm.^{3}. This would roughly correspond to a hole 2 miles in diameter and half a mile deep, of the same size as Barringer Crater.

No fragments of the original Siberian meteorite have been found. Unfortunately, the area of central impact is marshy, and nearly twenty years elapsed before the first exploratory expedition under Kulik arrived (1927), so it is fairly certain that any small fragments disappeared during that period. Kulik convinced himself that he had actually crossed the spot where the meteorite had fallen. The heated gases must have spread out in all directions from the point of impact, carrying devastation around, and either overthrowing the trees, or tearing or burning off their branches, as a photograph of the area shows. About ten shallow craters were found with diameters of 10 to 50 metres and of an average depth of 4 metres.

Kulik was unable to excavate the ground in search of fragments, but reckoned the area affected at hundreds of square kilometres.

Now, the velocity of the meterorite that formed the Barringer Crater may have been much smaller than 60 km./sec. The kinetic energy varies as the square of the velocity; hence at only 30 km./sec. the energy would have been four times smaller.

To offset this, the mass of the meteorite has to be assumed to be four times larger to excavate the same-sized crater. It is therefore reasonable to suppose, as Öpik and La Paz have done, that the Barringer crater was produced by a body weighing several million tons.

Now can we obtain a reasonable idea of its size? Assuming that it was of mixed stony and nickel-iron material, its density would have been about 5 g./cm.^{3}—the same as the meteoritic material from the crater. Again, assuming for the mass the lower limit of 10^6 tons or 10^{12} g., its volume would have been $0{\cdot}2 \times 10^{12}$ cm.^{3}. Very roughly then, we can think of the meteorite as a spherical body having a diameter of 75 metres.

It can be seen, therefore, that in most examples of meteor craters, a standard meteorite impact will account for all the facts, without bringing in any contra-terrene material.

In fact, if the matter is taken further, to the extent of examining or calculating suitable orbits for these bodies, it is seen that they fit very well into the category of captured terrestrial satellites, search for which is being undertaken at the undermentioned observatory. That, however, is another story[4].

ALAN F. COLLINS.

The Observatory, Dundry,
Nr. Bristol, Somerset.

6th January, 1959.

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The Satellite Telescope

SIR,

Mr. Smith appears to have fallen into a number of errors in his reply[1] to my comments[2] upon his design[3] for a satellite telescope. It is evident that I have not exaggerated the difficulties, in that I have given quantitative examples which anyone may check and which Mr. Smith therefore cannot refute.

I certainly did not suggest that the Cassegrain secondary mirror should be supported from the outer shell of the telescope, but that its supports should run immediately inside this shell to minimize thermal misalignment of the optics. It is absurd for Mr. Smith to quote the inverse square law as authority for saying that "closer examination reveals this conception to be false" and that "a structure running along just inside the shield is subject to thermal radiation many orders of magnitude higher than the structure [he] suggested": the inverse square law, of course, refers to a point source of radiation. The telescope tube, with its black lining of low thermal conductivity and an aperture of only about one-twelfth of its total surface area, approximates rather well to a black-body cavity, and it follows that the radiation density within it is everywhere practically the same. This does not, however, imply that the temperature of every part of the structure will remain precisely constant with time: there will naturally be a nett entry of heat on the sunlit side and a corresponding loss on the shaded side, and this heat transfer, although quite slow, is likely to impair the optical performance of the instrument. If we rather generously allow coma of $\frac{1}{90}$ sec. of arc, the centering tolerances are such that the pole of the secondary must be within 0·014 in. and its centre of curvature within 0·028 in. of the optical axis of the primary mirror.[4] In Mr. Smith's design, a temperature difference between opposite secondary mirror supports of only 0·4° C. would misalign the instrument by this maximum amount. It is of interest to note that the off-axis aberrations inherent in the use of a paraboloidal primary will limit the field of view covered in near-theoretical definition to the order of size of a planetary image—a fraction of a minute of arc or a few millimetres on the photographic plate—even with a perfectly adjusted telescope.

Mr. Smith is clearly driven to desperate lengths in his efforts to deny that the movements of an observer would cause guiding errors in the telescope that are anything short of disastrous. On the one hand, he twice asserts that the observer will be sitting comfortably (whatever "sitting" may mean in zero gravity) and on the other he admits that the maximum degree of permissible movement is that of one finger through 2 in.! Now, it is plain for all to see that even if the observer had the advantage of terrestrial gravity to hold him firmly in his chair he could not hope, let alone desire, to keep so still for any appreciable time, while without gravity the situation would be still more impossible. As for the discomfort (of, presumably, being shackled rigidly in a chair with only one finger free to move, and that only 2 in.) passing unnoticed on account of the mental stress of observing, this is also surely fallacious: with photoelectric guiding, the space astronomer would be at least as bored as his terrestrial counterpart.

If, however, his job can be accomplished by the exertion of one finger, the astronomer is redundant and should be replaced by electronics; if not, then at least the telescope should be designed so as to place him at the centre of gravity of the instrument, where his movements can do relatively little harm.

Yours sincerely,

ROGER GRIFFIN.

The Observatories,
University of Cambridge,
Madingley Road, Cambridge.
13 *March*, 1959.

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Design of Step Rockets

SIR,

In answer to the remarks of Mr. Cross[1], I would like to point out that the number of steps of a rocket is not assigned arbitrarily.

The first rule is that a rocket shall have as few steps as possible, because each additional step can be a source of trouble.

On the other hand, the minimum number of steps is limited by the fact that owing to the equation

$$p = r\,\frac{s-1}{s-r}$$

the individual mass-ratio r must be smaller than the structural ratio s.

But in practice the lower limit is determined by the fact that for small values of $(s - r)$ the payload ratio p increases enormously.

Furthermore, the number of steps is determined by the highest admissible acceleration. For a lower number of steps the maximum acceleration is higher for equal burning times.

Therefore in practice the number of steps used for a certain astronautical purpose differs at the utmost by one. For a circuit orbit, we have a marginal three steps (*Vanguard*) or a more common four steps (*Explorer*). For a Moon-rocket we need four steps.

I do not agree with Mr. Cross that a fractional step has a real physical interpretation. I maintain that the

number of steps can only be an integer. If a step rocket has a booster, this booster should be counted as a separate step with its own parameter. My formula:

$$P = R.\frac{s_1 - 1}{s_1 - r_1}.\frac{s_2 - 1}{s_2 - r_2}.\ldots\ldots\ldots\ldots.\frac{s_n - 1}{s_n - r_n}$$

gives a simple means of calculating the payload ratio for a step rocket with parameters which are different for each step.

My principal objection against a non-integral number of steps is of a theoretical nature. There is already so much confusion in this field that I think a rigid treatment to be advisable.

Yours truly,

M. VERTREGT.

73, Mozartlaan, The Hague,
Netherlands.

REFERENCE

1 C. A. Cross, *J.B.I.S.*, 1959–60, **17**, 31.

The Nuclear-Powered Ion Rocket

SIR,

In his recent letter[1] Dr. Leitmann derives some relations, in particular the mass distribution between working fluid and power plant, for a nuclear-powered ion rocket. His results are applicable to a model* given in an earlier paper[2] which he had modified by imposing on it a fixed amount of total energy (e_o) per unit initial mass of the rocket. This energy, developed during the firing time, is, it can be inferred from his letter, a constant; it can, of course, be written as $e_o = (p/K_1)t_b$. This additional restriction on the model gives rise to certain conditions that are not explicitly dealt with by Dr. Leitmann but which are perhaps sufficiently interesting to mention here.

There is in the first place, however, some question of the appropriateness of the modification It is not easy to visualise a type of power plant that would correspond to this modified model. Since p is variable (in order that the optimum mass distribution in the rocket may be selected) while e_o and K_1 are not, it follows that the firing time (t_b) is inversely proportional to p. Thus, for example, if it is expedient to halve the power plant mass the firing time *must* be doubled. This does not seem to be a desirable restriction on the designer nor is it a characteristic limitation of normal nuclear or solar power plants. The working life of a fission reactor, for instance, does not increase in inverse proportion to its mass, a β emitter has a definite half-life independent of its mass and a solar power plant's lifetime is presumably not specifically mass dependent. It is possible to postulate a thermonuclear reactor with power output proportional to mass and an amount of fuel, all of which was required to be used, that was fixed and a negligible proportion of the rocket's mass: this would satisfy the initial requirement but it would be a quite implausible restriction on the use of the fuel. The original model of reference[2] provides a more reasonable approximation to reality; any limit on the total power per unit mass of power plant (rather than unit mass of rocket) is accounted for by placing an upper limit on t_b. t_b is in fact already limited by considerations of allowable voyage times, and the analysis is directed to reconciling it with the other design parameters.

The aptness of the model aside, Dr. Leitmann's conclusions are correct. However, one degree of freedom has been lost by his additional restriction on the model and so in his expression for the acceleration,† a constant in this case, V_e and t_b are no longer (for the required condition of $p + f(1 + K_2) =$ constant) independently variable, since e_o contains both p and t_b. Thus when the acceleration is maximized [$p = 2f(1 - f)(1 + K_2)$] all the parameters are uniquely defined, and the unfortunate astronaut who finds, for example (and it depends on the value prescribed for e_o) that his rocket's firing period is agreeably short but that its characteristic velocity is insufficient to take it to its destination just has to lump it—or depart from his condition of optimum acceleration. For the corresponding relation‡ derived from Ref. (2), V^2_e/t_b is a maximum when $p = f(1 - f)(1 + K_2)$.§ V_e and t_b are then still adjustable and so can be made to suit the particular voyage under consideration, a result presumably more satisfactory to the astronaut.

Yours sincerely,

H. PRESTON-THOMAS.

National Research Council,
Ottawa, Canada.
20th March, 1959.

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* *For which it was postulated that:* the power output $P = \frac{1}{2}\dot{M}V^2_e$ is independent of exhaust velocity (V_e) and proportional to power plant mass (pM_o); the mass of the working fluid containers (K_2fM_o) is proportional to the mass of the working fluid originally carried (fM_o); and the power available is not time-dependent. The nomenclature is that of the reference paper.

† $\dfrac{dV}{dt} = \dfrac{V_e}{t_b} = \sqrt{\dfrac{2}{e_oK_1^2}\cdot\dfrac{f}{1-f}\cdot p^2}$

‡ $\dfrac{dV}{dt} = \dfrac{Vc}{t_b} = \sqrt{\dfrac{2pf}{t_bK_1(1-f)}}$

§ *Note added in proof.* This distribution can always provide, at one and the same time, a smaller e_o, a higher V_e, a higher AK_1, and a smaller t_b/K_1 than is obtained from the alternative mass distribution of Ref. 1.

REPORT OF COUNCIL

FOR THE YEAR ENDED 31 DECEMBER, 1958

CHAIRMAN'S ADDRESS

A remarkable expansion in the rate of astronautical development has characterized the year that has elapsed since I prepared my last address to the members of our Society. During that period a large number of successful launchings of artificial satellites have taken place and two probes have been projected completely beyond the influence of the Earth's gravitational field to become eternal wanderers in interplanetary space. These events signify the fact that Astronautics has now become one of the major areas of scientific and technological development, a situation which must now have a profound effect on the future of the B.I.S. and similar societies in other countries.

While astronautics even in its more rudimentary form lay entirely in the future it was possible for a society such as ours to proceed on a fairly modest basis relying largely upon voluntary help to carry out its day to day business. The Society has operated in this way for many years, its income from membership subscriptions being too small to meet such commitments as the *Journal* and ***Spaceflight*** and, at the same time, finance an adequate administrative headquarters. In the circumstances, thanks to the Secretary, the Editors and a handful of other enthusiasts who have taken on considerable duties for little or no remuneration, it has been our policy to concentrate our resources on publications and other visible activities which have constituted a positive contribution to astronautics. As a result we have been able to build up a valuable reputation for the Society which is an essential foundation for its future.

In the more positive phase of space research and exploration which we have now entered we must recognize the need for placing all our activities upon a more solid footing. Among other things this will mean strengthening the headquarters staff, a matter which I consider, should be given the maximum priority. To survive in this new age of astronautics we shall need to increase the volume of our publications and improve their quality and we must hold more meetings of a significant professional character than we have done in the past. This short report of the state of the Society and its activities during the past year will reveal that we are beginning to move in the right direction, though I think it must be clear to everyone who has studied the annual financial statement, that any significant improvement in our status must depend upon a continuing increase in revenues. Finance is the keynote to our future and it is appropriate that we should carefully examine the state of the Society's revenues in any assessment of our present or future capabilities.

The Financial Status of the Society

The financial statement of the Society was published in the March-April issue of the *Journal* and I assume that you will have examined the figures given therein. On the whole, the situation appears fairly satisfactory, particularly as compared with 1957, when a substantial deficit was incurred. The accounts show that the revenue for the period from 1 January to 31 December, 1958 exceeded that for the previous fifteen month period (*i.e.*, 1 October, 1956 to 31 December, 1957) by 33%. It must be remembered, of course, that part of the increase was due to the raising of the subscription rates, which accounted for an additional increment of about £1,500 per year. However, it will be noted that a significant contribution to the improvement has stemmed from other revenue sources such as sales of publications, advertising and royalties. In my last address, when I set out the case for increasing the membership subscription rates, I stressed that other channels through which money might flow into the Society were being explored. So far, the attempts to open alternative income channels have met with partial success, but it is pertinent to enquire to what extent these can be kept open or even enlarged.

In all instances the new sources of income have been exploited as a result of the diligence of the Secretary and his staff. The encouraging income from royalties must also be regarded to a large extent as a donation from authors who have published papers in the *Journal*. This income, of course, will only continue if the Society can supply more material to interested publishers and it depends, therefore, upon the willingness of authors and editors to provide such material. On the other hand it is apparent that advertising as a serious source of income has not been exploited to any significant degree by the Society up to the present time, and this is a field which offers a major challenge to us for the future. It is equally clear that the Society is not deriving any benefit from an increase in membership and this is, consequently, a matter of some concern.

While the 1958 accounts may give us some degree of satisfaction, the situation provides no cause for complacency. The Society needs further considerable increases in revenue to meet a number of requirements. I would list as the main items which will set a demand for greater expenditure the following:

(*a*) the need to increase the strength of the administrative staff;

(*b*) the need to publish the *Journal* monthly and ***Spaceflight*** bimonthly, or even monthly.

(*c*) an expansion of B.I.S. activities in other fields, for example in organizing symposia, exhibitions, introducing awards;

(*d*) possible rising costs due to national inflationary trends;

(*e*) eventual establishment of the London headquarters in more suitable premises.

At the present time there is an urgent need to spend £2,000–£3,000 per annum on strengthening the staff complement. An increase in the frequency of the publication of the *Journal* to a monthly rate would demand a further £4,000 per annum, while a further £1,200 per year would be needed to make ***Spaceflight*** bimonthly. These figures do not allow for any rise in printing costs which might well occur, if present demands for wage increases are met, but even so they represent an increase in expenditure equivalent to about 70% of the 1958 income. If the increase in revenue during 1958 could be maintained then we could achieve this result by the end of 1960. However, it cannot be emphasized too strongly, that the maintenance of such a rate of increase calls for a tremendous effort on the part of the staff and officers of the Society and the general membership should not take for granted the possibility of a continuing expansion.

I have stressed the need for increasing the headquarters staff, because the present situation is not one that can be maintained indefinitely. The Secretary has continued to

work for the Society on a part-time basis and for a nominal stipend with an inadequate staff. The work involved grows at an alarming rate and the fact that the London Office is able to deal with it is a great tribute to their energy and enthusiasm. It is worth noting, by way of example, that during 1958 no less than 20,000 letters were written and this, of course, represents only one facet of the day to day administration. Obviously, therefore, the Society must take on further paid staff and this is a matter of considerable urgency.

In my previous address I drew attention to the need for extending the Society's premises. I can now record that this has been done and, by acquiring the first floor of 12 Bessborough Gardens, we have doubled the available accommodation. I do not regard this as a full satisfaction of our eventual requirements, since the general condition of the building and its situation leave much to be desired. However, any further development in this direction, such as the eventual transfer to other more suitable premises, can be postponed without jeopardizing the efficient running of the Society.

Publications

In 1958 we returned to the bimonthly frequency of publication of the *Journal*, but the flow of material for publication is now so great that despite the increased number of issues the stockpile of papers awaiting their turn to appear in print has grown to undesirable proportions. It is, of course, comforting to the Editor to know that he has ample material in hand to see him through a number of future issues, but, on the other hand prospective authors are not encouraged to publish in any journal in which the delay in appearance of their papers is likely to be excessive. The need for expansion of the *Journal* is therefore extremely pressing and while it does not yet appear to be financially feasible to double the publication frequency, we shall nevertheless strive to make each bimonthly issue as large as possible.

The major recent development in the *Journal* publication policy has been the change to the larger format; the Editor has also taken advantage of this opportunity to introduce certain typographical improvements. The new page size corresponds more closely to other scientific and technical journals and is exactly in line with ***Spaceflight.*** So far, the reaction of members and subscribers appears to be highly favourable and the Council is satisfied that the change has been a step in the right direction. The new *Journal* size will lend itself more readily to future expansion than the old size would have done.

There can be no change at present in the frequency of publication of ***Spaceflight,*** though, naturally we would all wish to see it appear more often as soon as the Society's finances will permit. From the start ***Spaceflight*** has been edited by Mr. Patrick Moore, who has given much of his valuable time and effort to this duty. It was with regret that the Council accepted his resignation, when he was finally forced to give up the Editorship. I would like to record here an expression of the Society's appreciation for the great work which he did during his period of office.

I cannot conclude these remarks about our publications without emphasising my firm conviction that they should be given the highest priority of all the Society's activities. The publication of a first-class scientific journal and an attractive, informative and accurate popular magazine remain the major objectives of the B.I.S. In the capable hands of Mr. G. V. E. Thompson and Mr. K. W. Gatland (who succeeds Mr. Moore as the editor of ***Spaceflight***) I am sure that these two organs of the Society will continue to flourish and improve.

Society Meetings and Other Activities during 1958–59

The period under review began with the 9th I.A.F. Congress at Amsterdam and I am pleased to record that our Society was very strongly represented at that meeting. When we left Amsterdam, we did so with the I.A.F.'s commission to hold the 10th International Astronautical Congress in London in 1959. As a result, one of the major preoccupations of the officers of the Society during the past few months has been the organization of this important meeting which is to take place during the week 31 August–5 September. On the basis of the growth of the I.A.F. Congress during recent years, we are anticipating that the attendance should be in the region of 500 participants. This, by any standards, constitutes a fairly considerable gathering and it will be appreciated, very readily, that a further heavy burden is being added to the well worn shoulders of the Secretary and other officers of the Society. I would like to take this opportunity of appealing to the members, particularly in the London area, to come forward and offer their services. The need for volunteers will be particularly acute in the two or three weeks before the conference and, of course, during the actual meeting. Those who feel that they are able to help in any way are invited to write to or call upon the Secretary.

The Commonwealth Spaceflight Symposium, which is scheduled to occupy three days in the week preceding the I.A.F. Congress is an interesting and, we hope, valuable experiment. The object of the Symposium is to gather together representatives from the Commonwealth to present papers and enter into discussions on the subject of the Commonwealth's capabilities in the field of astronautics. It is intended that the papers should deal with technical, economic and political aspects of the subject. The Vice-Chairman, Mr. Gatland, is responsible for organizing the programme of the Symposium and he has already had an extremely favourable response from industrial organizations in the matter of preparing papers for presentation at the meeting. There is every reason to believe that this will be a useful and successful gathering. I should add that my appeal for assistance from members applies also to the Commonwealth Symposium.

A special feature of the past year was the occurrence of the 25th Anniversary of the British Interplanetary Society and the occasion was celebrated by dinners in London and in our provincial branches. I had the honour of presiding over the London function and derived particular pleasure from my attendance at the celebrations of the Midlands and Western Branches. In London, we marked the anniversary, also, by holding a two-day symposium on Space Medicine. This was the first time the Society had attempted to hold a specialized conference, as distinct from a general astronautical meeting. The response turned out to be very satisfactory and we have been encouraged to consider the question of holding further symposia dealing with single specialized aspects of spaceflight. The papers which were presented at the Space Medicine Symposium will be published in due course and should provide an interesting addition to the literature of the subject.

Membership

Although I have been able to record an encouraging improvement in the financial position, I must record that there has been no corresponding increase in the number of members. The number of members in all grades has shown only a very small increase over the level reported in my last address. This state of affairs is somewhat disappointing and I feel that renewed efforts must be made to attract more people into both the Fellowship and Membership grades. In this matter, of course, every member of the Society can help, by drawing the attention of interested persons to the existence and work of the B.I.S. and encouraging them to join.

I recorded in my last address that the Council intended to introduce new proposals for a revised membership structure. The main object of doing so was to meet the criticism that the status of our Fellowship grade fell below that of other professional Societies. The Council's recommendations have been submitted to you and you will have had the opportunity of voting on them. These recommendations are really a compromise which takes into account the desire of many of

our members to have a Fellowship grade of high standing, but which recognizes that, at present, there still does not exist in the U.K. an established astronautics profession which could provide the criteria upon which Fellowship qualifications might be based.

The Council, Committees and Officers

At the time of preparing this address no definite step has been taken to co-opt any additional members to the Council in order to bring the number up to the total of fifteen authorized at the last Annual General Meeting. During the past year we have continued to function with twelve members on the Council and these members have shared a very high proportion of the committee duties of the Society. In the present election of Council members we have taken the opportunity of filling the vacancies.

During the year there was one change in the membership of the Council, Dr. W. R. Maxwell being co-opted to take the place of Dr. Brosan, who resigned. Mr. E. T. B. Smith, who has left the U.K. for two or three years to take up an appointment in Washington, with the British Joint Services Mission, also tendered his resignation. However, the Council considered that it might be useful to have a representative in the U.S.A. and Mr. Smith has accordingly agreed to withdraw his resignation and continue serving on the Council for the period for which he was elected (expiring in 1960).

The Council and its main committees have continued to meet frequently throughout the year. One or two of the committees, for example, the Technical Policy Committee, have had to yield to the over-riding priority of the Congress Committee, which is responsible for co-ordinating the preparations both for the I.A.F. Congress and the Commonwealth Spaceflight Symposium. However, the situation should be restored to normal in the next session and those committees which have been temporarily neglected will be restored to active life.

It has been a privilege for me to have been able to serve for a further year as Chairman of the Council and I should, particularly, like to express my appreciation to my colleagues on the Council for their co-operation during this period. In turn, on behalf of the Council, I should like to extend sincere thanks to the Secretary, Editors and Branch Officers for the continued services which they have given so freely to the Society.

Mr. R. A. Smith

I cannot conclude this address without commenting briefly upon the sad loss of our old colleague Mr. R. A. Smith, who was Chairman of the Society during 1956–57. Ralph Smith was one of the pioneers of the B.I.S., who, particularly in the immediate post war years, helped to reconstruct the Society and lay the foundation for its present position. He was one of the real enthusiasts, to whom the Society owes so much and whose role will not be forgotten in the history of our development.

L. R. SHEPHERD,
Chairman of Council.

MEMBERSHIP

The number of members in the various grades at 31 December, 1957 and 1958, were as follows:

	1957	1958
Honorary Fellows	5	5
Fellows	885	1007
Senior Members	51	99
Members	2247	2148
	3188	3259

COUNCIL AND OFFICERS

Chairman
L. R. SHEPHERD, B.Sc., Ph.D.

Vice-Chairman
K. W. GATLAND, F.R.A.S.

Ordinary Members of Council
D. J. CASHMORE, M.Sc.
S. W. GREENWOOD, B.Sc., M.Eng., A.M.I.Mech.E., A.F.R.Ae.S.
D. HURDEN, B.A., Grad.I.Mech.E.
N. H. LANGTON, M.Sc., Ph.D., A.M.Brit.I.R.E., A.Inst.P.
W. R. MAXWELL, B.Sc., Ph.D.
P. MOORE, F.R.A.S.
W. N. NEAT, B.A., A.F.R.Ae.S.
A. E. SLATER, M.A., M.R.C.S., L.R.C.P., F.R.Met.S.
E. T. B. SMITH, B.Sc., D.C.Ae., A.M.I.Mech.E., A.F.R.Ae.S.
G. V. E. THOMPSON, B.Sc., B.Sc.(Eng.), A.R.C.S., F.R.I.C., A.I.L., L.I.M.

Secretary:
L. J. CARTER, A.C.I.S.

COMMITTEES

The main committees of the Society which have served during the year were constituted as follows at 31 December, 1958:

FINANCE AND GENERAL PURPOSES COMMITTEE

SHEPHERD, Dr. L. R. (*Chairman*) — GATLAND, Mr. K. W. G.
CARTER, Mr. L. J. — THOMPSON, Mr. G. V. E.

I.A.F. COMMITTEE

SHEPHERD, Dr. L. R. (*Chairman*) — GATLAND, Mr. K. W.
CARTER, Mr. L. J.

JOURNAL PUBLICATIONS COMMITTEE

SHEPHERD, Dr. L. R. (*Chairman*) — SLATER, Dr. A. E.
CASHMORE, Mr. D. J. — THOMPSON, Mr. G. V. E. (*Editor*)
LANGTON, Dr. N. H.

MEMBERSHIP COMMITTEE

THOMPSON, Mr. G. V. E. (*Chairman*) — LANGTON, Dr. N. H.
HURDEN, Mr. D.

SPACEFLIGHT EDITORIAL BOARD

MOORE, Mr. Patrick (*Chairman and Editor*) — CROSS, Mr. C. A.
HURDEN, Mr. D.
COLEMAN, Miss A. — SLATER, Dr. A. E.

TECHNICAL POLICY COMMITTEE

SHEPHERD, Dr. L. R. (*Chairman*) — LANGTON, Dr. N. H.
CARTER, Mr. L. J. — NEAT, Mr. W. N.
CASHMORE, Mr. D. J. — SMITH, Mr. E. T. B.
GATLAND, Mr. K. W. — THOMPSON, Mr. G. V. E.
GREENWOOD, Mr. S. W.

I.A.F. CONGRESS COMMITTEE

SHEPHERD, Dr. L. R. (*Chairman*) — LANGTON, Dr. N. H.
CARTER, Mr. L. J. — THOMPSON, Mr. G. V. E.
GATLAND, Mr. K. W.

Commonwealth Spaceflight Symposium Sub-Committee

GATLAND, Mr. K. W. (*Chairman*) — STRICKSON, Mr. L.
ALLWARD, Mr. M. F. — ROSS, Mr. H. E.
DEMPSTER, Mr. D.

Ladies Congress Sub-Committee

CARTER, Mr. L. J. (*Chairman*) — GATLAND, Mrs. D.
ALLWARD, Mrs. M. F. — KUNESCH, Mrs. C.
CARTER, Mrs. H. — SHEPHERD, Mrs. L.

NEWS AND ANNOUNCEMENTS

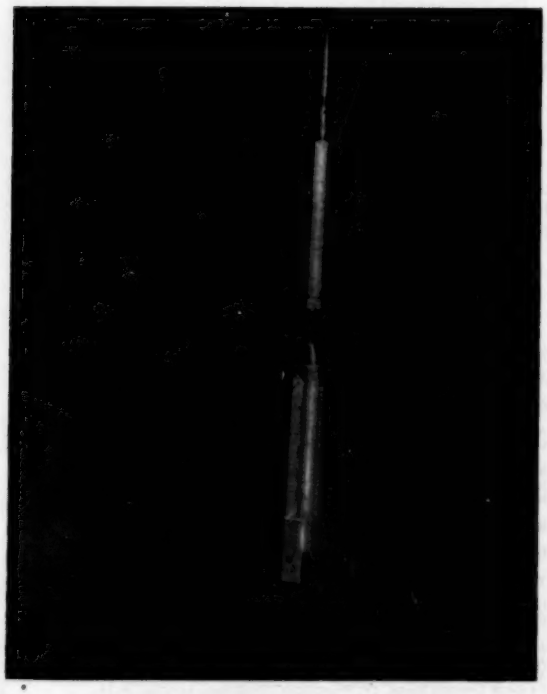
COMMONWEALTH NEWS

The Use of Long Tom and Aeolus for High-Altitude Experiments

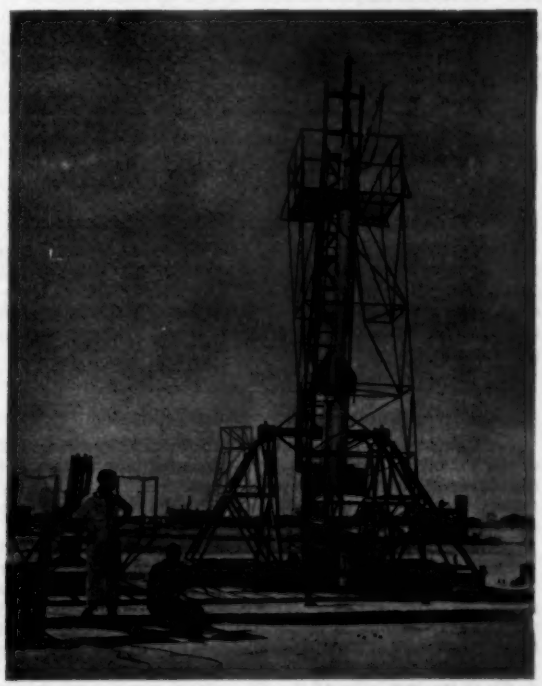
Long Tom and Aeolus are two rockets, designed and built at the Weapons Research Establishment, Salisbury, Australia, in the last two years, to assist in the development and calibration of both ground and airborne instrumentation installed at the Woomera Range. The characteristics of both these vehicles are such that, besides their primary function as range sighter vehicles, they are both valuable rockets for exploration of the atmosphere to heights of the order of 100 miles. Some experiments have already been conducted along these lines, and further work is planned; in some of these trials, Weapons Research Establishment staff are collaborating with Australian Universities.

Both Long Tom and Aeolus are two-stage vehicles. They are boosted off the launcher by one set of rocket motors and accelerated to supersonic velocities. The boost motors burn out after about three seconds and are then jettisoned. The second stage then coasts on up to about 30,000 ft. altitude when its motor is ignited. During this second burning stage, the rocket accelerates rapidly: Long Tom reaches a velocity of about 4,000 miles/hr. and Aeolus about 3,000 miles/hr. by the time the fuel in the second stage is exhausted. After burn-out of the second stage, the rocket coasts on up to its peak altitude, the maximum altitude reached depending on the amount of payload carried and the angle of elevation at launch. Long Tom can carry 50 lb. of instruments to about 100 miles; with 150 lb. of instruments the peak altitude is about 65 miles. With the same payloads, Aeolus reaches about 45 miles and 35 miles respectively.

The overall length of Long Tom at launch is 27 ft., and the weight is nearly a ton. Aeolus is 21 ft. long and weighs about half a ton. Both are fired from the same launcher, and both have the same size compartment for instrumentation. This compartment is at the front of the second stage rocket and consists of a cylinder 3 ft. long and 9 in. diameter. This compartment can be pressurised to maintain sea level conditions for the instruments throughout flight, and provision is made to recover the instrument compartment by parachute. If no parachute recovery is used, the rocket impacts at about 3,000 miles/hr. and is completely destroyed. By using a suitable parachute, impact velocities can be kept to about 20 to 30 miles/hr. and this allows recovery and re-use of the



Long Tom on launcher at Woomera



Aeolus on launcher at Woomera

instruments. The successful deployment of a parachute from such high speed bodies would normally be extremely difficult —the air forces would rip the fabric to shreds. The means of overcoming this difficulty in these experiments is to separate the instrument compartment from the main rocket by an explosive cutting charge at some very high altitude, generally about 40 miles, and stream the parachute immediately. The air density at these altitudes is less than one-thousandth of its value at sea level and the air loads are correspondingly reduced. As the air density gradually increases during the fall, so the air loads on the parachute gradually increase and the instrument compartment is slowed without heavy shock loads on the instruments or the parachute fabric.

Typical trials which have been carried out, or are planned for the future, are the measurement of micrometeorite prevalence at high altitudes and the measurement of wind patterns in the altitude range 20 to 40 miles. The micrometeorite experiment, which is being conducted in conjunction with the Australian National University, involves the measurement of the frequency with which meteoric dust strikes a sensitised portion of the missile; each impact is telemetered to the ground. The measurement of wind patterns in the atmosphere can be carried to heights of about 20 miles by normal meteorological balloon tracking techniques, while above altitudes of about 40 miles, the Physics Department of Adelaide University has carried out extensive measurements of wind patterns by tracking the ionized trails of meteors. Rocket techniques are being used to fill the gap between 20 and 40 miles altitude, and this is one purpose to which Aeolus—named after the Greek god of the winds—is being put. At several heights between 20 and 40 miles, bundles of aluminium foil or metallised Nylon thread are ejected from the rocket. As these drift down, they are carried by the local winds; radar tracking of their course provides a measure of wind velocity and direction.

B.I.S. NEWS

The Printing Dispute and the Society's Publications

The prolonged dispute in the printing industry has led to considerable delays in the issue of both the *Journal* and *Spaceflight*. The editorial on p. 77 indicates the arrangements that are being made to overcome this situation with regard to the *Journal*; ***Spaceflight*** will also resume normal publication as soon as possible.

Election or Transfer to the Fellowship

The Special Resolution relating to the membership structure of the Society was approved by an overwhelming majority of members voting in the recent ballot and was adopted at the Annual General Meeting held on 17 July (to be reported fully in the next issue of the *Journal*).

The effect of this resolution is to introduce the new grade of *Associate Fellowship*, as from 1 October, 1959. Senior Members and Members who may be considering whether to apply for transfer to a higher grade are reminded that the Council intends to revise Bye-Laws 3 and 6 with effect from **1 October, 1959**. The new Bye-Laws were printed in the Agenda for the Fourteenth Annual General Meeting on p. 61 of the last issue of the *Journal*.

The effect of the revision to Bye-Law 3 is to require all applications submitted after the specified date to be on a new type of form. Copies of this are already available and may be obtained on request from the Secretary.

The changes to Bye-Law 6 introduce the requirements for the new grade of Associate Fellowship and also tighten up the requirements for the Fellowship.

Benevolent Fund

Since the announcement a few months ago of the establishment of the Society's Benevolent Fund, contributions amounting to about £200 have been received. This is in addition to the £250 allocated by the Council from the Society's general monies, and forms a useful step towards the target of £3000 which is regarded as the minimum to establish the Fund on a firm basis. The money subscribed to the Fund will be invested and it is desirable that grants made to beneficiaries should be made out of the income of the investments rather than from the capital itself.

Any grants made from the fund during its early stages must necessarily be limited, but nevertheless it should not be regarded as something abstract and not for immediate use. The Trustees have already made a grant of £50 to the widow of a member, and will be ready to consider other cases meriting assistance which may be brought to their notice. Members are reminded that the Fund has been established as a means of alleviating distress caused to members or their dependents by disablement or bereavement, etc., and that initially any member of the Society of more than five years' standing (or his or her dependents) is eligible for assistance. Benefits from the fund will not be restricted to members in the United Kingdom or British Commonwealth, but will be available to members resident anywhere.

The Trustees of the Fund will normally be informed of the death of a member and will then be able to enquire whether any assistance is needed. They would be grateful if other cases meriting consideration could be brought to their attention.

The Trustees and the Council of the Society wish to express their thanks to all who have already contributed to the Benevolent Fund. They will welcome further contributions—as mentioned above, the initial target is £3000.

Western Branch Secretary

Mr. G. L. Garthwaite has resigned his position as Secretary of the Western Branch, and Mr. R. Sykes (21, Mackie Grove, Filton, Bristol) has been appointed Branch Secretary in his place.

Election of Members

The following elections were made at the Council Meeting on 7 February, 1959:

New Fellows.

NASIR UDDIN AHMED, B.Sc., Atomic Energy Commission, Government of Pakistan, Karachi.
ALLAN GEORGE BOWMAN, 24, Haversham Drive, Bracknell, Berkshire.
LEONARD DACRE E. BRODIE, 2, Upper Park Drive, Forest Town, Johannesburg, Transvaal, South Africa.
BRIAN ANTHONY COLLETT, B.Sc., 40, Arthray Road, Botley, Oxford.
JOHN BERTRAM LEWIS COOK, B.Sc., 2, Millward Road, Ryde, Isle of Wight.
ROBERT JAMES DANIELS, B.Sc., 2, Russell Avenue, High Lane, Nr. Stockport, Cheshire.
ROGER MARTIN FLINN, M.B.Ch.B., Sen Sook, Far End, Sheepscombe, Nr. Stroud, Gloucestershire.
ERNEST ERWIN FELDMESSER-REISS, M.D., St. Lawrence's Hospital, Bodmin, Cornwall.
YASHAWANT GHARPURE, B.Sc., Green Villa, Street No. 2, Dhantoli, Nagpur India.
GILBERT RATCLIFFE HADFIELD, 12, Nettleton Road, Ickenham, Middlesex.
CRAIG WILSON HARTSELL, M.S., 22700, Kittridge Street, Canoga Park, Calif., U.S.A.
JOHN EDMUND HODGES, 18, Moredon Park, Swindon, Wiltshire.
ALAN RICHARD HOLMES, 14, Westgate Road, Newbury, Berkshire.
STEPHEN HOTHER-LUSHINGTON, B.Sc., 3, Hetton Road, Leeds 8, Yorkshire.
FRANCIS GEORGE JONES, 19, Wynchgate, Southgate, London, N.14.
ANTHONY FRANK KING, 6, South Avenue, Chellaston, Derbyshire.
DAVID BROOME LLOYD, B.Sc., 7, Aldbourne Avenue, Earley, Reading, Berkshire.
JOHN BRIAN MCGARRY, B.Sc., Ph.D., 9, Elizabeth Drive, Church Crookham, Aldershot, Hampshire.
DONALD CHARLES MCINNES, 12, Vine Street, Lincoln.
DENIS FRANCIS REARDON, B.Sc., 22, Franconia Road, Clapham Park, London, S.W.4.
RODNEY SHAW, B.Sc., M.A., 5, Hillside Crescent, Newsome, Huddersfield, Yorkshire.
THOMAS TELFORD, M.Sc., Stockhill, Brayton, Aspatrio, Cumberland.
ROY FRANK WHITELAND, 45, Charter Road, Forest Gate, London, E.7.

Members elected to the Fellowship.

LEONARD GEORGE AUDRITT, 134, Lennox Drive, Swindon, Wiltshire.
IAN VICTOR HANSFORD, B.Sc., 3, Withdean, Cavendish Road, Weybridge, Surrey.
ROBERT HARDY, 'West by Nor,' Colwell Lane, Totland, Isle of Wight.
WILLIAM DOUGLAS HODGSON, B.A., 28, Shaftesbury Street, Burnley, Lancashire.
HARRY JOHN IVEY, B.Sc., 'White Walls,' Runymore, Shaldon, South Devon.
IZHAK JACOBSON, B.Sc., 58, Hakeshet Street, Ramat-Gon, Israel.
WOLFGANG BENJAMIN KLEMPERER, Dip. Ing., D.Sc., 738, South Bristol Avenue, Los Angeles 49, Calif., U.S.A.
EZRA CESAR LEVY, M.S., 520, N. Highland Avenue, Los Angeles 36, Calif., U.S.A.
KURT DORON OFER, B.Sc., Dip.Ing., 14, Gordon Street, Haifa, Israel.
THOMAS FRASER SANDMAN, M.B., Ch.B., 397, Lanark Road, Edinburgh, 13.
DAVID HERBERT YOUNG, A.M.I.Mech.E., 118, Abbotsbury Gardens, Eastcote, Pinner, Middlesex.

Members elected to Senior Membership

WALTER FREDERICK ATHILL, 15, Port Hill, Hertford, Hertfordshire.
DENNIS EDWIN ARTHUR BARNES, 261, London Road, West Croydon, Surrey.
PETER DAVID BURCH, 19, Edmunds Avenue, St. Paul's Cray, Kent.
FREDERICK ALFRED ETTRIDGE, 14, Minerva Drive, Watford, Hertfordshire.
L. STUART FORSYTH, 7, Seymour Gardens, Anerley Road, London, S.E.20.
ROBERT GEOFFREY HALSTEAD, 51, Woodlands Drive, Harrogate, Yorkshire.
GERALD HOLLIS, 24, Ashfurlong Road, Dore, Sheffield.
PERCIVAL CYRIL HUBBARD, 20, Fitz-George Avenue, London, W.14.
FRANK ROSLING, 2, Midville Close, Ermine West, Lincoln.
PETER WILLIAM SHAW, 124, Onslow Gardens, Wallington, Surrey.
JAMES SILCOCK, 'Halfways,' Hadlow Lane, Willaston, Wirral, Cheshire.
ARTHUR D. STANNELLS, 371, St. Albans Road, Hatfield, Hertfordshire.
RICHARD SUTER, 19, Central Avenue, Manly, N.S.W., Australia.
ROY IRVING TOPLIS, 46, Kew Green, Kew, Richmond, Surrey.
JOHN EDWARD WESTFALL, 2513, Piedmont Avenue, Berkeley 4, Calif., U.S.A.
ROGER REAY WHITCUTT, 270, Little Brays, Harlow, Essex.
JAMES WHITE, 10, Riversdale Gardens, Finaghy, Belfast, Northern Ireland.
ROBERT OCTAVIUS WOODS, 56, Dunmore Avenue, Trenton 8, N.J., U.S.A.
RALPH HARRY WILFRED YOUNG, 107, Strathmore Road, North Gosforth, Newcastle, 3.
CHARLES ZIMMERMAN, 7, Stanley Gardens, Kensington, London, W.11.

New Members.

CHRISTOPHER DAVID ALLAN, B.A., 300, Foleshill Road, Coventry.
TONY ASQUITH, 54, Troy Road, Morley, Nr. Leeds.
PATRICK GEORGE ATKIN, 37, Currie Street, Hertford.
FLOYD BARGER, 22, Roosevelt Street, Garden City, N.Y., U.S.A.
LUCY CLARA BEHENNA, 39, Ebury Street, Westminster, London, S.W.1.
MICHAEL JAMES S. BELTON, 'Old Hall View,' Gainsborough, Lincolnshire.
BENJAMIN HUNGERFORD BLAND, 61, Hanover Road, Willesden, London, N.W.10.
GEOFFREY J. BOURKE, c/o Navy Office, Stout Street, Wellington, New Zealand.
DAVID KEITH BROWN, 151, Uxbridge Road, Hampton Hill, Middlesex.
VICTOR JAMES CHADWICK, 33, Delce Road, Rochester, Kent.
PETER RICHARD CLINK, 24, Preston Road, South Yardley, Birmingham, 26.
ERNEST FRANK COLLINS, "The Hollies," Sruton, Northallerton, Yorkshire.
GORDON COOPER, "Deepdene," Kidderminster Road, Wribbenhall, Bewdley, Worcestershire.
THOMAS FRANCIS CORCORAN, 24A, Showell Green Lane, Sparkhill, Birmingham 11.
ALEXANDER WILLIAM COWDEROY, 12, St. Pauls Close, Rock Ferry, Birkenhead, Cheshire.
DAVID JOHN DANCY, Boundary Hall, Tadley, Hampshire.
ANTHONY JOHN DAVIES, 70, Pine Road, Cricklewood, London, N.W.2.
THOMAS RAYMOND DEARLOVE, 8, Harlow Crescent, Harrogate, Yorkshire.
RAYMOND FAULKNER, Stoney Croft, Stoney Lane, Galgate, Lancaster.
CHARLES WILLIAM FRANKS, 117, Hundred Acres Lane, Amersham, Buckinghamshire.
TOBY FREEMAN, A.B., M.D., North American Aviation Inc., Medical Dept., Los Angeles 45, Calif., U.S.A.
DAVID HENRY GITTINS, 13, Glenferrie Road, St. Albans, Hertfordshire.
CHRISTOPHER JOHN HATTER, A.C.I.S., 38, Chalkhill Road, Wembley Park, Middlesex.
RONALD ALBERT HUMPHREYS, 30, Crescent Rise, Wood Green, London, N.22.
HAROLD GEORGE HUTCHINGS, P.O. Box 427, Ndola, Northern Rhodesia.
GORDON MICHAEL KENNARD, St. Andrew's House, 31, Farnborough Road, Farnborough, Hampshire.
LAURENCE EDWARD KING, 19, Rollins Street, Old Kent Road, London, S.E.15.
MICHAEL TETSUO KISHIMOTO, B.Ec., Apt. 15, 103–13th North, Seattle 2, Washington, U.S.A.
PETER LAVIN, B.A., 118, Oakbank Avenue, Chadderton, Nr. Oldham, Lancashire.
HAROLD ARTHUR LLOYD, 6, Halfhides, Waltham Abbey, Essex.
WILLIAM ANTHONY MACCALLUM, 11, Ravenscraig Terrace, Glasgow, S.W.3.
SOLOMON JOSEPH F. MAGUIRE, Clontallaghan, Kinawley P.O., Enniskillen, Co. Fermanagh, Northern Ireland.
ALAN DAVID MEAKIN, 253, Carr Road, Northolt, Middlesex.
CHRISTOPHER GEORGE MEANLEY, Grove House, Melton Constable, Norfolk.
ROBERT STANLEY B. NOAKES, 18, Alsace Street, Bagshot Street, London, S.E.17.
LEONTYNA MARY M. OPIELA, Flat 2, 15, The Beeches, West Didsbury, Manchester, 20.
DOUGLAS WAYNE ORCHISTON, 66, Milray Avenue, Wollstonecraft, Sydney, N.S.W., Australia.
JAN ODEHNAL, D.Sc., Caracas P.O. Box 2442, Venezuela.
JOHN STANLEY ORME, "Merrivale," 13, Wirksworth Road, Duffield, Derby.
ROBERT M. PAGE, M.S., Ph.D., 16844, Bollinger Drive, Pacific Palisades, Calif., U.S.A.
CECIL ALFRED PARTRIDGE, 56, Woodside Avenue, Cinderford, Gloucestershire.
JOHN PRIESTMAN PHILLIPS, 40, Keswick Drive, Whitley Bay, Northumberland.
COLIN GEORGE POND, 2, Castle Road, St. Albans, Hertfordshire.
JOHN ROSS, 35A, Coates Gardens, Edinburgh, 12.
HARRY VERNON ROTHWELL, 28, Mayfield Road, Northfleet, Kent.
KENNETH HERBERT SAYERS, B.Sc., 35 Frith Road, Bognor Regis, Sussex.
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JOHN WOODWARD, 318, Dyas Road, Great Barr, Birmingham 22 A.
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The following elections were made at the Council Meeting on 7 March, 1959:

New Fellows.

LESLIE JOHN STANLEY BRADBURY, B.Sc., 24, Churchfield Road, Walton-on-Thames, Surrey.
BENJAMIN JAY BRETTLER, Sc.D., 16, Burnham Road, Wenham, Mass., U.S.A.
HANEEF AKHTAR FATMI, B.E., 104105/19, Bohri Road, Karachi-2, West Pakistan.
ROBERT FORSYTH, B.Sc., 40, Linskill Terrace, North Shields, Northumberland.
MELVIN GEORGE GORDON, B.Sc., 1501, North Highland, Fullerton, Calif., U.S.A.
FRANK GRINSTED, B.Sc., Norrels Lodge South, Norrels Drive, East Horsley, Leatherhead, Surrey.
PHINEAS DAVID HANSTEAD, B.Sc., 21, Court Way, Hendon, London, N.W.9.
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BASIL EDWARD W. STANDLEY, 8, Roe Green Close, Hatfield, Hertfordshire.
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KWOK-PING YOUNG, B.E.E., 245, Henry Street, Brooklyn 1, N.Y., U.S.A.

Members elected to the Fellowship.

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JOHN ANTHONY DAVIDSON, Primrose Cottage, Whippingham, E. Cowes, Isle of Wight.
NORMAN GIBBONS, M.B.B.S., 20, Court Farm Gardens, Epsom, Surrey.

Members elected to Senior Membership.

ALFRED RONALD BEADLE, 9, Dartmouth Park Hill, Tufnell Park, London, N.W.5.
GERALD CAPALDI, 478, Keppochhill Road, Glasgow, N.1.
KENNETH WILLIAM HEWETT, 17, Kingsley Avenue, Southall, Middlesex.
JIM WILLIAM CHARLES JAMES, 4, Hampshire Road, County Park Estate, Hornchurch, Essex.
IAN DONALD MACRAE, 42, Clive Street, Revesby, New South Wales, Australia.
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New Members.

JOHN REGINALD BARKER, "Craglands," Ashopton Road, Bamford, Nr. Sheffield.
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RAY NAPOLEON MOSES, Tamassee, S.C., U.S.A.
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ERNEST RAYMOND WHITBY, W.O./Sgts. Mess, 47 G.W. Regt. (FD.) R.A., B.F.P.O. 20.

ASTRONAUTICAL ABSTRACTS

Edited by J. HUMPHRIES and J. FOLEY

1959–60 PARTS 3–4

A list of abbreviations of titles of journals was included with the 1954 index and addenda have been published in subsequent issues of the *Journal*. A further addendum is given below:

Amer. Ceram. Soc. Bull.	American Ceramic Society Bulletin.	*J. Roy. Soc. Arts.*	Journal of the Royal Society of Arts.
Battelle Tech. Rev.	Battelle Technical Review.	*M.I.T. Rocket Res. Soc. J.*	M.I.T. Rocket Research Society Journal.
Inst. Radio Engrs., Trans. Aero. Navig. Elect.	Institute of Radio Engineers, Transactions on Aeronautical and Navigational Electronics.	*Schweiz. Bauztg.*	Schweizerische Bauzeitung.
J. Appl. Math. Mech.	Journal of Applied Mathematics and Mechanics (U.S.S.R.).	*Trans. Soc. Inst. Techn.*	Transactions of the Society of Instrument Technology.

1—ASTRONOMY

[*See also* abstract no. 603.]

(564) **Some applications of control technique in astronomy**. P. B. Fellgett. *Trans. Soc. Inst. Techn.*, **11** (1), 24–38 (*March*, 1959). Interaction between astronomy and technology since 1789, current applications of control techniques (automatic guidance of telescopes, plate measurement, and photometry; the Leyden Southern Station "light-collector"); Schmidt optical systems, their close tolerances and control methods.

(565) **The detection of planets at interstellar distances**. M. H. Briggs. *J. Brit. Interplan. Soc.*, **17**, 59–60 (*March-April*, 1959). From recent developments in the theory of planetary origins and the probable relationship between the rate of stellar rotation and the presence of planets, it is suggested that the observed rate of rotation, and hence the spectral type of a star can serve as criterion for the existence of a planetary system. A survey of stellar rotations and spectral types of the nearest stars is given and the probable existence of life on the planets around these stars discussed.

(566) **Rocket observation of X-ray emission in a solar Flare**. (1) J. W. Warwick and H. Zirin; (2) T. A. Chubb *et al*. *Nature*, **180**, 500–2 (7 Sept., 1957). Two letters.

(567) **Scientists discuss Mars observations**. *Missiles and Rockets*, **2** (1), 19 (*Jan.*, 1957). A report of a symposium held in New York on Martian observations during 1956.

(568) **Gulliver's moons**. D. Malcolm. *Spaceflight*, **1**, 107–8 (*April*, 1957). Descriptions of Phobos and Deimos.

(569) **Polarimetric and photometric study of the polar cap and dark regions of the planet Mars**. J. H. Focas. *C.R. Acad. Sci., Paris*, **246**, 1665–7 (17 *March*, 1958). (*In French.*) (7 *refs.*)

(570) **Star Tracker to be Used in Study of Mars**. *Elect. Engng. N.Y.*, **78** (2), 191–3 (*Feb.*, 1959). Star tracker, infra-red recording system and other equipment to be used in U.S. Navy's *Stratolab* project to carry a 16-in. reflector and 3-in. Cassegrain telescopes to a height of 80,000 ft., using a manned balloon.

(571) **Lunar thermal radiation at 35 KMc**. J. E. Gibson. *Proc. Inst. Radio Engrs.*, **6**, 280–6 (*Jan.*, 1958). Investigation of variation of radio-wavelength brightness temperature with lunar phase shows complex rather than sinusoidal variation, varying between 225° and 145° K. Observations of two total eclipses showed no measurable change in lunar radiation occurs during the first few hours of an eclipse. Indications suggest that surface is composed of a layer of fine dust of very low thermal conductivity of average depth one inch or more.

(572) **Possible sources of a lunar atmosphere**. W. F. Edwards and L. B. Borst. *Science*, **127**, 325–8 (14 *Feb.*, 1958). Considers radioactive release, cosmic ray bombardment and primeval gases. (15 *refs.*)

(573) **Moondust**. J. Lederburg and D. B. Cowie. *Science*, **127**, 1473–5 (27 *June*, 1958). Studies of dust on the Moon may help an assessment of prebiotic synthesis of organic compounds and enable an empirical test to be made of the cosmic dissemination of biospores. (15 *refs.*)

(574) **The physical nature of the surface of the Moon**. G. Fielder. *J. Brit. Interplan. Soc.*, **17**, 57–8 (*March-April*, 1959). Evidence concerning the structure of the lunar rock is reviewed. It is probable that it is vesicular in nature. (6 *refs.*)

(575) **Meteors and spaceflight**. N. H. Langton. *Spaceflight*, **1**, 92–100 (*April*, 1957). Types and distribution, danger to spacecraft and protection by meteor bumper. (6 *refs.*)

(576) **Meteoritic dust and ground simulation of impact on space vehicles**. D. H. Robey. *J. Brit. Interplan. Soc.*, **17**, 21–30 (*Jan.-Feb.*, 1959). A general discussion of meteoritic dust is presented and deductions pertaining to the physical properties and probable speeds are given. It is believed that a large portion of atmospheric dust is generated in the atmosphere by the disintegration and ablation of meteors. Thus, the siliceous (glass-like) and magnetic (iron-nickel) spherules, which are found on the ground, are believed to originate at meteor altitudes from vaporized meteorites. A large quantity of smaller sized dust is believed to be cometary, either arriving directly from comets, etc., *per se*, or indirectly from exploding or disintegrating meteoroids. The possibility that a portion of the influx of meteoroids may contain a sizeable percentage of frozen molecular fragments has influenced the results. For example, from this hypothesis, the possibility of a dust cloud surrounding the Earth and extending out for several thousand miles has been suggested. Also, the correlation between prominent meteor showers and excessive rainfall, snow cover and cirrus cloud, can be explained on this basis. Finally, a proposal for accelerating dust particles to speeds of 10 miles per second, and possibly up to 18 miles per second, *in vacua*, is presented. (37 *refs.*)

6—ASTRONAUTICS

[*See also* abstracts nos. 572, 573, 655.]

(577) **Down-to-earth problems of space travel**. T. R. F. Nonweiler. *Aeronautics*, **37** (6), 50–1 (*Feb.*, 1951). Re-entry problems.

(578) **Air Force research and development in space technology**. T. S. Power. *Aero. Engng. Rev.*, **16** (9), 36–9 (*Sept.*, 1957).

(579) **Relativity and space travel**. (1) J. H. Fremlin; (2) H. Dingle. *Nature*, **180**, 499–500 (7 *Sept.*, 1957). Two letters.

(580) **Elementary considerations on satellite and space travel problems**. J. Ackeret. *Schweiz. Bauztg.*, **75**, 814–22 (28 *Dec.*, 1957). (*In German.*) (2 *refs.*)

(581) **On the solution of a degenerate variational problem and the optimum climb of a cosmic (space) rocket.** V. A. Egorov. *Priklad. Matermat. Mekh.*, **22**, 16–26. (*In Russian.*) (1958.) Also available in English edition: *J. Appl. Math. Mech.*, pp. 20–36. (4 *refs.*)

(582) **Towards space flight.** A. R. Weyl. *Aeronautics*, **38** (1), 32–5 (*March*, 1958). Review of recent literature.

(583) **Guided weapons and space flight.** E. Burgess. *Aeronautics*, **38** (2), 43–5 (*April*, 1958).

(584) **Research in outer space.** *Science*, **127**, 793–802 (11 *April*, 1958). Proposals put forward by the Technical Panel on the Earth Satellite Program, U.S. National Committee for the I.G.Y., National Academy of Sciences. Topics covered include the following: (*i*) *Sounding rockets.* (*ii*) *Light-weight-satellite experiments:* creation of visible objects; total atmospheric thermal and visible radiation measurements; mapping of the cloud cover; mapping of the night airglow and aurorae; time fluctuations of solar ultra-violet and X-radiation; distribution of hydrogen in space; survey of celestial sources in the far ultra-violet; extra-galactic light; cosmic ray investigations; primary auroral particles; micro-meteorites; magnetic field; ionospheric investigations; biological experiments. (*iii*) *Advanced satellite experiments:* selective and directional thermal radiation measurements; selective and directional ultra-violet and X-ray measurements; astronomical spectrograms; ultra-violet photographs of the Sun; planetary spectrograms; an experimental test of the general theory of relativity; solar (cosmic) radio noise in the high-frequency and low-frequency spectra; collection of micrometeoritic samples; manned satellites. (*iv*) *Lunar investigations:* measurement of lunar mass and gravity; direct measurement of the lunar magnetic field; mass spectrographic measurements of the lunar atmosphere; seismic and microseismic observations of the lunar crust; observations at the point of impact. (*v*) *Planetary and interplanetary investigations:* determination of the astronomical unit; determination of planetary masses; entry into planetary atmospheres; landing on the planets. (*vi*) *Manned spaceflight.*

(585) **Space program offered by Killian Advisory Committee.** *Science*, **127**, 803–5 (11 *April*, 1958). Extracts from report.

(586) **President's message on Space Agency.** *Science*, **127**, 864–6 (18 *April*, 1958). Setting up of National Aeronautics and Space Agency.

(587) **The development of space vehicles.** C. A. Cross. *Aeronautics*, **38** (3), 39–41 (*May*, 1958).

(588) **Space vehicles as thermodynamic systems.** A. E. Weller and F. L. Bagby. *Battelle Tech. Rev.*, **7** (5), 3–8 (*May* 1958). Aerodynamic heating problems relative to Earth and the other planets and dissipation of heat from vehicles in space.

(589) **Design of step rockets.** M. Vertregt. *J. Brit. Interplan. Soc.*, **17**, 30–31 (*Jan.-Feb.*, 1959). C. A. Cross, *ibid.*, 31. Letters. Graphical constructions for the parameters of a step rocket are discussed (cf. C., *ibid.*, 1957–58, **16**, 148).

(590) **Earth satellite has magnesium shell.** J. S. Kirkpatrick. *Civil Engineering*, **27**, 58–62 (*Jan.*, 1957).

(591) **Computation for an Earth satellite.** N. D. MacDonald. *Computers and Automation*, **6**, 6–9, 23 (*Feb.*, 1957).

(592) **General relativistic red shift and the artificial satellite.** B. Hoffmann. *Phys. Rev.*, **106**, 358–9 (15 *April*, 1957).

(593) **Radio tracking, orbit and communication for the Earth satellite.** J. P. Hagen. *Aero. Engng. Rev.*, **16** (5), 62–6 (*May*, 1957).

(594) **Role of the Earth satellite in four important I.G.Y. experiments.** R. W. Porter. *Aero. Engng. Rev.*, **16** (5), 89–93 (*May*, 1957).

(595) **Meteoric dust erosion problem and its effect on the Earth satellite.** S. A. Hoenig. *Aero. Engng. Rev.*, **16** (7), 37–40 (*July*, 1957). (16 *refs.*)

(596) **Next—the manned satellite.** W. von Braun. *Air BP*, (8), 2–5 (1958).

(597) **Satellite rocket problems.** A. D. Baxter. *Engr.*, **205**, 236–8 (14 *Feb.*, 1958). General requirements to reach orbital velocity, including mass ratio and the possibilities of weight reduction, motor performance and future limitations and reliability.

(598) **Temperatures of a close Earth satellite due to solar and terrestrial heating.** R. H. Wilson. *Science*, **127**, 811–2 (11 *April*, 1958). Radiation balance (6 *refs.*).

(599) **Orbital motion of the Earth satellite 1957 β from 1 April, 1958 to its decay 14 April, 1958.** G. R. Miczaika and E. W. Wahl. [*U.S.*] *Air Force Cambridge Research Center Report TN*58–445; *AD*–152 621. (*Available as PB* 151,249.) 38 pp. (*June*, 1958). The analysis is based on all positional observations available to Project Space Track prior to 22 May, 1958. Included in the study are descriptive reports of the decay phenomena.

(600) **Torques on a satellite vehicle from internal moving parts.** R. E. Roberson. *J. Appl. Mechs.*, **25**, 196–200, 287–8 (*June*, 1958). Derives a complete expression for the attitude perturbation torque from internal moving parts interpreting each of its terms. The attitude reference co-ordinate system is discussed. The nature of the torque is found for three simple cases. (1 *ref.*)

(601) **Fall of the Sputnik I rocket.** R. Jastrow and I. Harris. *Science*, **127**, 1499–1500 (27 *June*, 1958). Analysis of final phases suggests probable point of impact at latitude 45° N, longitude 106° E, in Outer Mongolia at 0846 GMT on 1 Dec., 1957. (1 *ref.*)

(602) **Research based on Sputniks I and II reported by Soviets.** *Science*, **127**, 1378–81 (13 *June*, 1958). Excerpts from an article published in *Pravda* on 27 April, 1958.

(603) **Satellite tracking: its methods and purpose.** E. G. C. Burt. *Endeavour*, **17**, 216–22 (*Oct.*, 1958). Radio, radar and optical methods with theoretical discussion of effects of Earths' oblateness and atmosphere. (10 *refs.*)

(604) **Methods for predicting the orbits of near Earth-satellites.** D. G. King-Hele and D. M. C. Walker. *J. Brit. Interplan. Soc.*, **17**, 2–14 (*Jan.-Feb.*, 1959). Methods are described for predicting the times and positions of the daily transits of a satellite, and the geometry of its orbit. The methods depend upon maintaining an accurate record of the period of revolution, from which the other orbital elements are deduced theoretically. (8 *refs.*)

(605) **Perturbations of elliptic orbits by atmospheric contact. II.—Some deductions from observations of the orbits of the first Russian satellites.** T. R. F. Nonweiler. *J. Brit. Interplan. Soc.*, **17**, 14–20 (*Jan.-Feb.*, 1959). Reviews information at present available concerning the action of air resistance on the orbit of the first Russian satellites, in the light of the theoretical treatment previously given by the author (*ibid.*, 1957–58, **16**, 368). As such it is treated as a continuation of this previous paper. It is found that the theoretical results on orbital decay are of use in determining certain features of the satellite, though for prediction purposes proper allowance for Earth oblateness is necessary. There is apparently a considerable variation from day to day in atmospheric properties within the ionosphere but mean conditions can be inferred. (13 *refs.*)

(606) **The satellite telescope.** F. A. Smith. *J. Brit. Interplan. Soc.*, **17**, 32 (*Jan.-Feb.*, 1959). A letter. S. replies to criticisms (Griffin, *ibid.*, 1957–58, **16**, 584) of S.'s design (*ibid.*, 1957–58, **16**, 361) for a manned orbital telescope.

(607) **Exclusive from Russia! Design details of the Lunik.** *Prod. Engng.*, **30** (5), 15–17 (2 *Feb.*, 1959). Describes the three-stage, 352,000-lb. vehicle (designated CH-10) used to achieve escape velocity on 2 Jan., 1959, launching and tracking methods. Exhaust velocities of 9,348–10,000 ft./sec. were obtained from tungsten carbide lined engines. *See also next abstract.*

(608) **Soviets reveal more details on Lunik design.** *Prod. Engng.*, **30** (7), 22–23 (16 *Feb.*, 1959). Lunik 3-stage vehicle now reported to weigh 332,000 lb. Two light-weight high-thrust boosters each weighed 4,862 lb., including 4,488 lb. propellent, said to be same as used for U.S. Thiokol rockets. Booster burned for 10 sec. providing 112·2 lb./ton/sec. thrust. Failure to hit Moon is now attributed to crudeness of mechanism to cut third-stage burning (had tolerance of ± 0.1 sec.).

(609) **The Venus probe.** F. A. Smith. *J. Brit. Interplan. Soc.*, **17**, 42–5 (*March-April*, 1959). The surface of Venus is hidden by the mantle of white clouds that continuously sweep across her. It is reasonable to suppose that before any spaceship lands upon her surface, a preliminary expedition will try to determine the nature of these clouds, and that of her atmosphere, and also the type of surface underneath. This study is concerned with examining the problems involved and with suggesting some possible

solutions. No attempt is made to lay down a detailed design as it is felt that engineering and radio techniques will have changed appreciably by the time that such a venture could be undertaken. (7 *refs.*).

(610) **Navigation in space**. J. M. Wuerth and J. M. Slater. *Automation Progress*, **3**, 4–6 (*Jan.*, 1958). Maintenance of orbit, inertial guidance and path determination.

(611) **Reconnaissance orbits**. A. A. Adler. *J. Brit. Interplan. Soc.*, **17**, 33 (*Jan.-Feb.*, 1959). S. W. Greenwood, *ibid.*, 33. Letters pointing out errors in G.'s discussion (*ibid.*, 1957–58, **16**, 534) of round-trip voyages from the Earth to other planets without landing.

(612) **Minimum gravitational losses for rocket motion near a planetary surface**. D. J. Cashmore. *J. Brit. Interplan. Soc.*, **17**, 52–7 (*March-April*, 1959). For a given effective mass-ratio, if a rocket achieves a smaller velocity increment in the presence of a gravitational field than it would in the absence of one, it is said to suffer "gravitational loss" during the period. In general, the gravitational loss depends on the shape of the trajectory and the acceleration régime. The case of take-off from or landing on a planet is considered. Minimum gravitational losses are incurred in a trajectory hugging the surface of the planet, and these are calculated for constant acceleration and constant thrust régimes. An approximate solution only is found for the latter case.

(613) **Manned navigation and guidance in the solar system**. D. J. Cashmore and C. N. Gordon. *J. Brit. Interplan. Soc.*, **17**, 46–51 (*March-April*, 1959). Inertial guidance techniques are proposed for the mid-course phases of manned interplanetary voyages. Star-trackers stabilize the orientation of a platform to the fixed stars, and the periods of motor operation are monitored by accelerometers. During periods of free fall, a digital computer predicts the trajectory of the vehicle. The gravity field is deduced from the configuration of the solar system, the co-ordinates of the planets, etc., being pre-recorded on magnetic tape or film. (4 *refs.*)

7—PROPULSION

[*See also* abstract no. 641.]

(614) **Rocket engine reliability**. A. G. Thatcher and H. A. Barton. *Ordnance*, **41**, 722–6 (*Jan.-Feb.*, 1957).

(615) **Notes on problems in combustion instability of rocket motors**. T. P. Torda. *Aero. Engng. Rev.*, **16** (11), 34–7, 47 (*Nov.*, 1957). (10 *refs.*)

(616) **German post-war development of a modern rocket power-plant**. *Flugwelt*, **10**, 159 (*March*, 1958.) (*In German.*)

(617) **The elementary theory of rocket propulsion systems**. L. K. Branson. *M.I.T. Rocket Res. Soc. J.*, **5** (1), 14–30 (*April*, 1958). (34 *refs.*)

(618) **The design of bell-shaped nozzles**. R. Roth. *M.I.T. Rocket Res. Soc. J.*, **5** (1), 5–7 (*April*, 1958).

(619) **Rocket propulsion**. J. E. P. Dunning. *J. Roy. Soc. Arts*, **106**, 476–510 (*June*, 1958). (4 *refs.*)

(620) **Solid-propellant rocket engineering**. R. D. Geckler and R. E. Davis. *Aero. Engng. Rev.*, **16** (8), 42–6, 51 (*Aug.*, 1957). (4 *refs.*)

(621) **How to estimate solid propellant rocket performance**. S. Dobrin. *Aviation Age*, **28**, 70–3 (*Feb.*, 1958).

(622) **Determination of combustion time lag parameters in a liquid bipropellant rocket motor**. G. B. Matthews. *University Microfilms* (*Ann Arbor, Mich.*) *Pub. No.* 23845, 300 pp. (1958).

(623) **Transverse wave and entropy wave combustion instability in liquid propellant rockets**. S. M. Scala. *University Microfilms* (*Ann Arbor, Mich.*) *Pub. No.* 23861, 151 pp. (1958).

(624) **Rockets at Melun**. *Alata*, **14** (152), 3–6 (*Feb.*, 1958). (*In Italian.*) Data on SEPR rockets.

(625) **Starters for motors which require decomposable liquid for their operation**. de Havilland Engine Co., Ltd. *Brit. Pat. Spec.* 792,650, 6 pp. (2 *April*, 1958). Special reference to hydrogen peroxide.

(626) **Rocket motor cooling systems**. de Havilland Engine Co., Ltd. *Brit. Pat. Spec.* 792,909, 5 pp. (2 *April*, 1958).

(627) **Rocket motors**. de Havilland Engine Co., Ltd. *Brit. Pat. Spec.* 793,300, 6 pp. (16 *April*, 1958). Rotating disc injector.

(628) **Rocket motors**. de Havilland Engine Co., Ltd. *Brit. Pat. Spec.* 793,689, 9 pp. (23 *April*, 1958). Layout of liquid-propellent motor.

(629) **An analytical study of turbulent and molecular mixing in rocket combustion**. D. A. Bittker. *N.A.C.A. Tech. Note* 4321, 22 pp. (*Sept.*, 1958).

(630) **Rockets burning pre-mixed gaseous propellants**. L. E. Bollinger. *Shell Aviation News*, **222**, 15–18 (*Dec.*, 1956).

(631) **Effect of nitric acid concentration on the consumption rate of propionic acid and its chloro derivative in combustion of liquid propellant**. E. E. Gates. *University Microfilms* (*Ann Arbor, Mich.*), *Pub. No.* 23094, 105 pp. (1957).

(632) **Burning-rate studies. Part 5. Effect of acid concentration on the consumption rate of various fuels with nitric acid**. A. G. Whittaker and H. Williams. *J. Phys. Chem.*, **61**, 388–94 (*April*, 1957). (9 *refs.*)

(633) **Smokeless powder for propulsion of missiles**. Aktiebolaget Bofors, *Swedish Pat. No.* 159,019 (28 *May*, 1957). (*In Swedish.*) Use of rare earth or thorium compounds in solid propellents to reduce dependence of burning rate on ambient temperature.

(634) **Liquid rocket propellants—is there an energy limit?** J. F. Tormey. *Aero. Engng. Rev.*, **16** (10), 54–8, 68 (*Aug.*, 1957).

(635) **Homogeneous solid propellants and the chemical industry**. L. G. Bonner. *Industr. Engng. Chem.*, **49**, 1344 (*Sept.*, 1957).

(636) **Applied research and product development for rocket propellants**. A. R. Deschere. *Industr. Engng. Chem.*, **49**, 1333–6 (*Sept.*, 1957).

(637) **Fluorine-derived chemicals as liquid propellants**. J. F. Gall. *Industr. Engng. Chem.*, **49**, 1331–2 (*Sept.*, 1957).

(638) **Liquid rocket propellants—is there an energy limit?** J. F. Tormey. *Industr. Engng. Chem.*, **49**, 1339–43 (*Sept.*, 1957).

(639) **Utilization of high-energy fuel elements**. E. A. Weilmuenster. *Industr. Engng. Chem.*, **49**, 1337–8 (*Sept.*, 1957). Boron fuels.

(640) **Propellents for space flight**. T. F. Dixon. *Air BP*, (9), 8–11 (1958).

(641) **On the selection of propellents**. M. Serruys. *Bull. Astr.*, (1), 12–24 (*April*, 1958). (*In French.*) Theoretical investigation of the operation of a rocket motor and the performance criteria for propellent selection.

(642) **On relativistic rocket mechanics**. J. M. J. Kooy, *Astronautica Acta*, **4**, 31–58 (1958). (6 *refs.*)

(643) **Propulsive properties of high intensity plasma jets**. A. C. Ducati and G. L. Cann. *Giannini Res. Lab. Report GRL TR-9*, 137 pp. (*Feb.*, 1958). (*Available as PB* 134,980.)

8—MISSILES

[*See also* abstracts nos. 580, 586.]

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(646) **Design of air frames for nuclear power**. C. L. Johnson and F. A. Cleveland. *Aero. Engng. Rev.*, **16** (6), 48–57 (*June*, 1957).

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(648) **Farnborough 1957.** *Aircraft Engng.*, **29**, 302–9 (*Oct.*, 1957). Photographs, mainly of guided missile exhibits at the 1957 S.B.A.C. display.

(649) **An evaluation of Russia's missile program.** R. E. Stockwell. *Autom. Ind.*, **118**, 103–4 (1 *Jan.*, 1958).

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(651) **Launching missiles from submarines.** G. Partel. *Riv. Maritt.* (*March*, 1958). (*In Italian.*)

(652) **Fabricating the Redstone missile.** *Steel*, **142**, 66–71 (20 *Jan.*, 1958). Uses largely aluminium alloys and produced with tools found in any well-equipped sheet metal shop.

(653) **Ballistic missiles.** T. R. F. Nonweiler. *Aeronautics*, **38** (1), 28–31 (*March*, 1958).

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(656) **Project Rockoon.** H. Friedman and J. E. Kupperian. *Military Electronics*, **2**, 12–14, 16 (*Jan.*, 1957).

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(659) **Optimization of rocket orbits. I. Idealized calculations.** K. W. Ford. *Los Alamos Scientific Laboratory LA-2166*, 33 pp. (*Feb.*, 1958). Thrust programmes for several kinds of rocket orbit optimization are derived and discussed for the case of a flat Earth.

(660) **Self-contained navigation systems.** R. W. West. *Aero. Engng. Rev.*, **16** (5), 96–8 (*May*, 1957).

(661) **Principles of self-contained navigation.** H. H. Bailey. *Aero. Engng. Rev.*, **16** (8), 68–73 (*Aug.*, 1957).

(662) **Effect of dynamic characteristics of rocket components on rocket control.** J. C. Sanders, D. Novik and C. E. Hart. *Aero. Engng. Rev.*, **16** (10), 73–7 (*Oct.*, 1957). (12 *refs.*)

(663) **Inertial guidance.** W. Wrigley, R. B. Woodbury and J. Hovorka. *Aero. Engng. Rev.*, **16** (10), 59–62 (*Oct.*, 1957).

(664) **Self-aiming as a problem of engineering cybernetics.** A. S. Kel'zon. *Dokl. Akad. Nauk, S.S.S.R.*, **116**, 933–6 (21 *Oct.*, 1957). (*In Russian.*) Choosing an automatic guidance system; analysis and synthesis of self-aiming guided missiles.

(665) **Aids to inertial navigation.** F. Stevens and F. W. Lynch. *Aero. Engng. Rev.*, **16** (11), 43–7 (*Nov.*, 1957).

(666) **An introduction to inertial navigation.** E. Large. *Brit. Comm. Elect.*, **5**, 20–5 (*Jan.*, 1958).

(667) **Missile control.** K. Garner. *Control*, **2** (9), 54–7 (*March*, 1959). Introduction to series of articles. Classification of guided missiles and methods of guidance. Brief glossary. See also next two abstracts.

(668) **Controlling guided missiles. 1.—Visual command guidance.** D. W. Allen. *Control*, **2** (9), 57–62 (*March*, 1959). Evolution of guidance systems, use of visual command control with German missiles, operator training and the man-machine system, wire and radio guidance links, missile aerodynamics, notes on current command guided weapons (*Vickers* 891, *Pye, Bullpup, Dart, SS*10, *SS*11, *SS*22, *Nord* 5103, *Cobra IV* and *Robot* 304).

(669) **Controlling guided missiles. 2. Aerodynamics: What a control engineer needs to know.** F. R. J. Spearman. *Control*, **2** (10), 96–101 (*April*, 1959). Considers the three-dimensional equations of motion and their conversion into transfer function form. Analysis for roll, pitch and yaw; examples of closed loop performance of autopilots.

BOOK REVIEWS

Vistas in Astronautics: First Annual Air Force Office of Scientific Research Astronautics Symposium (Co-Sponsored with Convair Division, General Dynamics Corporation). Edited by Morton Alperin, Marvin Stern and Harold Wooster. $9\frac{3}{4} \times 7\frac{1}{2}$ in. Pp. xxi + 330, illustrated, 1958, London: Pergamon Press (105s.).

In February 1957, an Astronautics Symposium was held in San Diego, California, jointly sponsored by the U.S.A.F. Office of Scientific Research and the Convair Division of the General Dynamics Corporation (builders of the "Atlas"). The occasion was the first of its kind in the United States; it had been conceived as a meeting of specialist enthusiasts on a relatively small scale, but "to our amazement" (to quote the editors' preface) it was attended by about 600 engineers and scientists.

Of course, one needs to remember that the date was 8 months B.S. I (Before Sputnik I).

The volume now under review "represents that portion of the Symposium which can be published without reference to restrictions imposed by national security" (who was keeping what secret from whom? Remember the date). The result is a fairly large and beautifully-produced book, which is what one would expect from Pergamon Press, and no more than one has a right to do, in view of its price.

No less than 44 papers are included, mostly by authors who will be well-known to B.I.S. members; Schriever, Eggers, Ferri, Whipple, Cornog, Stuhlinger, Sutton, Truax, Oberth, Strughold, Campbell, Simons and Haley are among them. The papers are presented in six parts: Re-entry, Tracking and Communications, Environment and Measurements, Propulsion, Orbits, and Human Factors. These headings, together with the quoted sample of contributors, should suffice to support the statement that the volume is fully comprehensive. Indeed, any critic would be severely taxed to name some aspect of astronautics which is not touched upon.

However, with all this, the present critic, at least, has to confess to some feeling of disappointment at the overall results. Nearly all the papers, even the most technical, are short and superficial; some of them extremely so. Any seeker after detailed knowledge would do much better to refer to other sources, in many cases to other papers by the same authors (most of those in this volume contain a useful list of references). In some ways, this particular criticism is perhaps an unfair one to make, in so far as it might be countered by the entirely logical answer that all the participants in the Symposium were required to do no more than prepare brief reviews of their particular subjects, to stimulate discussions, and that the criticism proves that they did exactly that. Nevertheless, potential purchasers should be warned that the resulting proceedings (which do not include the discussions that presumably took place) do not constitute an astronautical encyclopedia. The *Vistas* title is very apt and fair; what we have here is a summary of a great many exciting and interesting possibilities.

There are two senses in which *Vistas in Astronautics* can be wholeheartedly recommended.

First, it would be an excellent introduction to the subject for a technical reader with a serious and urgent desire to find out what it was all about, and who was prepared to go on to a course of further detailed study in particular aspects of it. Not, of course, for the layman, who would be much better served by various popular works—but he is unlikely to be able or willing to afford the five guineas in any case.

Secondly, the volume will be invaluable to future technical historians of astronautics, who will wish to study a representative cross-section of authoritative opinion in A.D. 1957. In this respect, it joins such other works as the volume of proceedings of the B.I.S./R.Ae.S. Cranfield Symposium, or (for a slightly earlier date) the B.I.S.'s "Realities of Space Travel." Much of the material in each of these, however, is both more original and more detailed than most of that in "Vistas," even if rather less comprehensive.

A. V. CLEAVER.

Satellites and Spaceflight. By Eric Burgess. $8\frac{1}{2} \times 5\frac{1}{2}$ in. Pp. vii + 159, illustrated. 1957. London: Chapman and Hall, Ltd. (21s.).

This book was written before the Russians showed the way beyond the atmosphere, and so Vanguard gets rather a lot of attention. The author deals in his usual manner, which appears

to be that of making a compilation of previous work and conclusions without much digestion, with the following topics: Instrumented Satellites, a Station in Space, Probing into Space, an Expedition to the Moon, The Lunar Base, and Interplanetary Flight. The chapter on Instrumented Satellites consists mostly of an introduction to the elementary concepts of extraterrestrial travel, such as escape velocity, mass ratio, and some comments on the properties of elliptical orbits. "Station in Space" deals with some of the environmental problems and some known proposals for manned satellites. "Probing into Space," "Expedition to the Moon," and "Lunar Base" are similarly concerned with the next stages in travel. "Interplanetary Flight" is a sketchy outline of distant problems.

A great deal of the book, to judge by the references, is based on, or extracted from, this *Journal*, so that members of the Society will have little need to buy "Satellites and Spaceflight." It is an inevitable fault of such books, prepared presumably in a hurry to catch a fairly transient interest, that they can deal thoroughly and competently with few of the topics that must be considered. Perhaps the general reader does not want very thorough treatment in his reading matter: he should at least have some assurance that the author is competent to write the book. In the present case, it is rather sad to note that in many instances the author's competence must be doubted.

E. T. B. SMITH.

Aircraft and Missile Propulsion. Volume I. Thermodynamics of Fluid Flow and Application to Propulsion Engines. By M. J. Zucrow. 9 × 5¾ in. Pp. xiv + 538, illustrated. 1958. New York: John Wiley and Sons, Inc. ($11.50); London: Chapman and Hall, Ltd. (92s.).

According to the author's preface, "*The present book is the first of a three-volume work, entitled* AIRCRAFT AND MISSILE PROPULSION, *which discusses the underlying principles of the technology pertinent to the following propulsion engines: the turboprop, the turbojet, the ramjet, the liquid-propellant rocket, and the solid-propellant rocket. This volume* (*Volume I*) *is concerned with the* THERMODYNAMICS OF FLUID FLOW AND APPLICATION TO PROPULSION ENGINES. *Volume II is concerned with the analysis of the cycles and the performance characteristics of the aforementioned propulsion engines, and Volume III will deal with components of those engines. Although* AIRCRAFT AND MISSILE PROPULSION *is written primarily for the engineering student and for the engineer who is not a specialist in propulsion, it is hoped that the work will also be useful to the engineers working in the fields of aircraft and missile propulsion. The prime objective of the work is to furnish the student and the practicing engineer with an understanding of the fundamental principles governing the functioning and operating characteristics of the engines employed for propelling high-speed aircraft and missiles.*" The reviewer has always doubted that engineers use textbooks on subjects outside their own specializations, and is therefore examining the book for its suitability for students and for practicing engineers in the propulsion field.

The book is divided into five main sections: (1) Review of Fundamental Principles, (2) General Characteristics of Propulsion Systems, (3) Thermodynamics of Compressible Fluid Flow, (4) Flow through Nozzles, (5) Flow through Diffusers. The rocket engine receives attention, but the main emphasis is on air-breathing systems.

The subject of thermodynamics and gas dynamics is treated fairly extensively, although the value of doing this is doubtful, as there are already a number of excellent texts covering much the same ground. In dealing with the fundamental aspects of propulsion it seems a pity that room could not have been found for more material on boundary layers and on heat transfer.

On the subject of propulsion the text at times reveals a lack of "feel" for the subject that will be apparent to practicing engineers. An example of this is to be found in the section on "The Turboprop Engine" (pages 113–117), where the turboprop is described as "a promising power plant for the propelling of aircraft in the moderately high-speed range." The three references quoted in this section are all dated prior to 1950. The "promise" has been fulfilled by British aero-engine manufacturers since that date and some excellent accounts of their work are available in the published literature.

The references quoted throughout the book vary widely in their usefulness; many of them refer to early articles of little current value. The entire text would profit from a fairly drastic revision with a view to reducing the amount of material on each subject to the minimum necessary for the presentation of an argument, and adding fresh material in an attempt to make the text more comprehensive. One feature of the book stands out as deserving special commendation, and will appeal particularly to students. Many worked examples are given throughout the text, and a number of exercise problems are included with their answers.

S. W. GREENWOOD.

La Propulsion par Fusées. Par Marcel Barrère, André Jaumotte, Baudouin Fraeijs de Veubeke, et Jean Vandenkerckhove. 25 × 16 cm. Pp. xi + 389, illustrated. 1957. Paris: Dunod. (5600 fr.).

This is a well-written book which deals with both solid and liquid rocket motors. Although some experimental information is included, and there are illustrations and brief descriptions of representative examples of motors for which information has been published, the work is mainly concerned with the theory of the subject. This is laid out in a clear and concise manner which is on the whole easy to follow, although in parts the nomenclature used is not that with which the British reader will be most familiar.

As is to be expected in a joint work by four authors, the space devoted to different subjects is not always proportional to their importance. For example, many pages are devoted to the theory of the instability of liquid propellent motors, although a good deal of this, while of considerable theoretical interest, is—unfortunately—of little practical importance. On the other hand, no space is devoted to the design of star-centred charges, although these are very common in modern solid propellent motors. There are, however, not many instances of this kind.

The book, which has a paper cover, is clearly printed on good quality paper. At the end of each chapter is an extensive bibliography selected from a wide variety of international sources. The photographic reproduction could sometimes be improved (*e.g.*, Fig. 3.5), but the line figures and graphs are very clear. Unfortunately, however, some of the captions and parameters on these can hardly be read with the unaided eye (*e.g.*, Fig. 5.16 and 6.2).

La Propulsion par Fusées is a useful addition to the rather small number of technical books on rocket motors and should find a place on the bookshelves of many people working in this field.

W. R. MAXWELL.

Advances in Geophysics. Volume 3. Edited by H. E. Landsberg. 9 × 5¾ in. Pp. x + 378, illustrated. 1956. New York: Academic Press, Inc. ($10). London: Academic Books Ltd. (72s.).

This volume contains one contribution of direct astronautical interest, namely "Geophysical Research with Artificial Earth Satellites", by S. F. Singer (pp. 301–367; *University of Maryland, Physics Dept. Tech. Report No.* 53). This is a useful survey, based on seventy-nine references, of various geophysical measurements which can be made with artificial satellites: investigation of terrestrial magnetism, the shape of the Earth and gravitational anomalies, the Earth's albedo, weather, upper atmosphere phenomena, solar and cosmic radiation, meteoritic particles, the energy balance of the Earth, and solar/terrestrial relationships. It concludes with a discussion of the limitations imposed on satellite applications by design characteristics.

The other papers in the volume are "Antarctic Island Research", by A. P. Crary (pp. 1–41; 53 ref.); "Recent Developments in the Study of the Polarization of Sky Light", by Zdenek Sekera (pp. 43–104; 32 ref.); "Subcontinental Structure in the Light of Seismological Evidence", by Perry Byerly (pp. 105–152; 98 ref.); "Heat Flow through the Deep Sea Floor", by E. C. Ballard, A. E. Maxwell and R. Revelle (pp. 153–181; 44 ref.); "The Interior of the Earth", by J. A. Jacobs (pp. 183–239; 127 ref.); "Subsurface Geophysical Methods in Ground-Water Hydrology", by P. H. Jones and H. E. Skibitzke (pp. 241–300; 64 ref.). There is an author index covering all the names mentioned in the references.

G. V. E. THOMPSON.

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